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RICHARD ALAN HACKING, O.B.E., M.Sc., F.I.M.

RICHARD ALAN HACKING is Technical Advisor on iron and steel production and development at Messrs. Richard Thomas and Baldwins, Ltd. Born at Darwen, Lancashire, and educated at Darwen Grammar School, Mr. Hacking began his industrial career in 1916 in the laboratory of the Darwen and Mostyn Iron Co., Ltd., and received his technical education at the College of Technology, Manchester, and, after serving in the naval branch of the Royal Air Force, at Victoria University, Manchester. In 1922 he graduated with a first-class honours degree of B.Sc. in metallurgy, and was awarded an industrial bursary by the commissioners of the 1851 Exhibition.

After a further period of two years with the Darwen and Mostyn Iron Co., Ltd., Mr. Hacking joined the Park Gate Iron and Steel Co., Ltd., Rotherham, as a technical trainee, under the able guidance of Mr. Fred Clements. In 1925 he became a member of the metallurgical staff; in 1926 assistant blast-furnace manager, and he succeeded Dr. T. P. Colclough as chief metallurgist in 1928. Two years later he received the degree of M.Sc. at Victoria University, Manchester; he also holds the Sorby and James Taylor Prizes of the Sheffield Metallurgical Association.

Mr. Hacking joined the Central Research Department of Messrs. Dorman, Long and Co., Ltd., in 1938, and in 1941 was appointed Controller of Production of all the iron and steel works of the company. He was made a special Director in 1944. In 1946 he joined Messrs. Richard Thomas and Baldwins, Ltd., as Technical Advisor and was appointed a Director of the Steel Company of Wales, Ltd., in 1947. The award of the O.B.E. was made to him in the New Year Honours List of 1947.

For many years Mr. Hacking was an active member of the Joint Research Committees of The Iron and Steel Institute, which are now part of the British Iron and Steel Research Association, of which body he is a Member of Council. He is a member of numerous committees of the British Iron and Steel Federation, the British Standards Institution, and other bodies. He is a Founder-Fellow and a Vice-President of the Institution of Metallurgists. Mr. Hacking has been a Member of The Iron and Steel Institute since 1929, and was elected to the Council in 1945.

R. A. Hacking, O.B.E., M.Sc., F.I.M.
Member of Council

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Climatic Effects on the Corrosion of Steel

By J. Dearden, M.Sc., A.M.I.Mech.E., F.I.M.

SYNOPSIS

An attempt was made to correlate the corrosion of steel in a moderately industrial atmosphere with the hours of rainfall registered by a recording rain gauge. No such relation was found, as only 35–40% of the total corrosion occurred during the hours when the rainfall was sufficient to register on the gauge. A further 35–40% was due to the effects of humidity, and the balance is presumed to have occurred during periods of drizzle and when the specimens remained wet after recordable rainfall had ceased.

Measurements were made of the corrosion rate of previously rusted specimens under various humidities, and a marked increase in the rate was observed when the relative humidity was over 80%. A quantitative estimate of the corrosion due to rainfall and to various ranges of humidity has been attempted.

Observations were made on the effects of the weather prevailing at the start of exposure, the annual shedding of rust, the expansion when this cannot occur, and the sulphur content of rust formed under various conditions.

WIDE variations in corrosion rate according to local climatic conditions having been revealed by the work of the Corrosion Committee,[1] it was thought that corrosion might possibly be related to the actual hours of rainfall at the place of exposure in preference to the total hours exposed. A communication to this effect has been published.[2]

The subject was associated with the wear and corrosion of steel rails, and it was thought that variations in climate might have an effect on the rate of wear.

An experiment was therefore started outside the L.M.S. Research Laboratory at Derby with the object of determining whether any relation could be established between corrosion and hours of rainfall.

CORROSION SPECIMENS

Specimens 4 × 4 in. were cut from $\frac{1}{16}$-in. panel steel (reference *BWK*) of the following analysis :

Carbon	0·07%
Silicon	Trace
Manganese	0·29%
Sulphur	0·027%
Phosphorus	0·008%
Copper	0·11%
Chromium	0·10%
Nickel	0·05%

The steel was in the annealed condition and had a diamond hardness of 97 kg./sq. mm. The specimens were de-oiled and their surfaces given an emery finish by a linisher machine. Two $\frac{1}{8}$-in. dia. holes were drilled near the upper corners for suspension purposes.

EXPOSURE CONDITIONS

At the beginning of the experiment the following series of specimens were exposed :

Series I was suspended vertically about 10 ft. above the ground on the south-west side of the Derby Laboratory with the specimens facing south-west. The ground was covered with tar macadam.

Series II was suspended vertically in an open-air staircase 10 ft. above ground covered with concrete at the laboratory where the specimens were exposed to all the elements except rain.

Series IV was exposed at 45° to the vertical, on the roof of the laboratory, facing north. The undersides of the specimens were 2 ft. above the flat roof which was covered with a black waterproof compound.

Series V was suspended vertically about 4 ft. above grass-covered ground, facing west, in a rural atmosphere 2 miles north of Derby.

Series III, VI, and VII were exposed subsequently to the above and details are given later in the paper. All were exposed in the same position as series I.

None of the series was situated near any wall, and apart from series IV, all specimens were fully exposed to the weather on both sides.

At a later date series IX was exposed vertically outside the laboratory, but only while rain was falling. On returning to the laboratory after each exposure to rain, the specimens were dried with hot air and stored in a warm dry place until the next exposure. The object of this series was to obtain a very accurate record of the hours of rainfall to which the specimens were exposed.

Manuscript received 7th April, 1948.

Mr. Dearden is Chief Metallurgist at the Scientific Research Department, British Railways (London Midland Region).

MEASUREMENT OF CORROSION

Specimens were weighed before exposure, removed periodically and de-rusted, and again weighed. De-rusting was carried out in Clarke's solution (concentrated hydrochloric acid with an inhibitor). This solution dissolves only the rust, but in order to allow for any possible attack on the iron a weighed " blank " specimen was immersed in the solution for the same period as the corroded specimen. Any loss in weight from the " blank " specimen was then deducted from the gross loss of the corroded specimen.

RAINFALL

The hours of rainfall were read off and integrated from the charts of three recording rain gauges belonging to Derby Corporation and situated in different

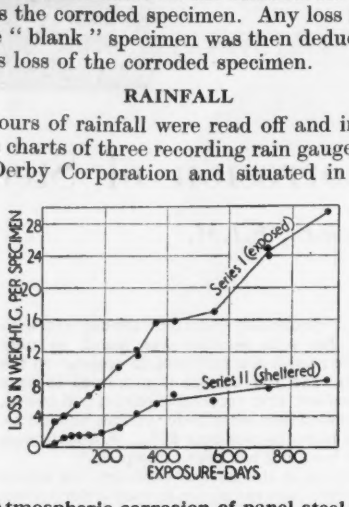

Fig. 1—Atmospheric corrosion of panel steel, 4 in. sq. × $\frac{1}{16}$ in., at Derby

parts of the town. Hours of snowfall were excluded from the count. During the three years the recorded rainfall at Derby averaged 1·1 hr./day and the average rate of fall during those hours was 0·06 in./hr., equivalent to 17 hr./in.

This rate of fall seems rather high when compared with figures given by Bilham[3] for various stations throughout the country. These range from 17 to 25 hr./in., and the difference is probably due to variations in the sensitivity of the recording gauges, and the method of integrating the hours of rainfall from the charts.

A rain gauge was installed outside the laboratory and 10% of the rainfall was collected and tested monthly for *p*H value by the L.M.S. Paint Section, with the following results :

Rainfall at Derby Laboratory, 1944	6·35 (mean) 4·55–7·42 (range)
Thunder rain on 29th May, 1944	5·5
Derby tap-water on 17th December, 1943	7·8
Distilled water	6·16
Sheffield rain water[4]	4·3

The rain collected in the Derby laboratory gauge is therefore slightly on the acid side of neutral, but less acid than Sheffield rain water.

CORRELATION WITH THE WEATHER

The corrosion losses for series I and II have been plotted in Fig. 1 on a basis of the number of days exposed, and it is seen that after 2·5 years the specimens exposed to the rain have suffered about 3½ times the corrosion of those specimens sheltered from the rain.

The difference between the losses in series I and II was originally taken as representing the corrosion due to rain alone and has been plotted in Fig. 2 on a basis of (*a*) exposure-days and (*b*) rain-hours. The similarity between the two graphs shows that there is no advantage in plotting the results on a rain-hour basis for one exposure station. This is because the rain-hours are proportional to the exposure-days over a long period of time.

A fresh approach was therefore made by exposing pairs of specimens for short periods of 2–4 weeks and attempting to correlate the difference between the losses from the exposed and sheltered specimens of each pair with the recorded rain-hours during this period. Out of 17 pairs of specimens exposed in this way at different seasons, the " difference " per rain-hour varied from 0·1 to 0·015 g., with a mean of 0·05 g. This wide variation is ascribed to differences in the rate of drying after rainfall had ceased. There was certainly no connection between corrosion due to rain and the recorded rain-hours.

It was realized that the method of measuring the rain-hours did not give a true measure of the total time for which the exposed specimens were wet. For instance, they could be wetted by drizzle insufficient to affect the recording gauges, and again when rainfall ceased there would be a period of drying during which the specimens would continue to corrode. It was therefore concluded that the method of recording the difference between the losses in series I and II as representing the corrosion due to rain alone was unsatisfactory. This led to series IX which was exposed only while rain was actually falling, and stored in a warm dry place in the laboratory at other times.

The average duration of each exposure to rain was about 3 hr. The results are plotted on a rain-hour basis in Fig. 3, from which it is seen that the corrosion during rainfall alone is 40–50% of that previously estimated from the difference between series I and series II. It is also 35–40% of the corrosion due to rainfall and humidity combined, under the conditions of exposure as described.

This confirms Hudson's statement[1] (*loc. cit.*, p. 213P) to the effect that *direct* rainfall is not the dominant factor in the atmospheric corrosion of steel, and that humidity and atmospheric pollution are mainly responsible. Schikorr[5] came to a similar conclusion after a 2-years' corrosion experiment in Berlin.

Taking the average recorded duration of rain as 1·1 hr./day, the results from series IX suggest an

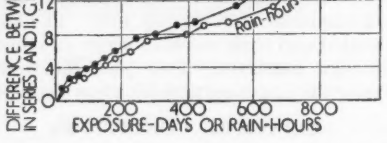

Fig. 2—Difference between corrosion losses on exposed and sheltered specimens (series I and series II)

annual corrosion loss of about 5·6 g. per specimen debitable to the direct effect of rain. The results of series II suggest that a further 5·7 g. per specimen can be debited to humidity. This leaves a "missing quantity" of 3·4 g. to make up the total annual loss of 14·7 g. suffered by series I as exposed to all the elements during the first year.

The "missing quantity" suggests that the series I specimens were wet for longer than the average period of 1·1 hr./day. This could occur during periods of drizzle or condensation insufficient to affect the recording gauges, and during periods of drying after recordable rainfall had ceased. An average of 1·8 hr./day is necessary to account in full for the annual loss of 14·7 g. per specimen in series I.

Another reason for the "missing quantity" is to be found on page 245. The rust on the series IX specimens contained only a trace of sulphur, whereas that on specimens fully exposed to the weather contained about 1% of sulphur which would stimulate corrosion at all times.

HUMIDITY CORROSION EXPERIMENTS

Having confirmed the importance of humidity in promoting corrosion, it was decided to attempt some measurement of its effect. Specimens were first exposed in a room controlled at 70° F. and 65% relative humidity. Higher humidities were obtained in a humidor installed in the same room and containing a dish of salt solution which controlled the relative humidity at 81% or 91% according to the salt used. When the dish contained water, the relative humidity was assumed to be 100%.

Bright emery-finished specimens of panel steel failed to show any sign of rusting or any gain in weight after 21 days' exposure to each of the above humidities. Recourse was therefore made to previously rusted specimens taken from series I and II after 128 days' exposure in an open and in a sheltered position respectively. Loose rust was brushed off and the moisture content of the adherent rust was stabilized overnight in a desiccator. A further 24 hr. in the desiccator produced no change in weight. The same treatment was applied to the specimens before re-weighing after each exposure in the humidor.

A measure of the corrosion was obtained from the increase in weight of the specimens, and this has been plotted in Figs. 4 and 5. The broken lines show the equivalent increase in weight for series IX (exposed to rain only) and series II (open air, sheltered from rain), the values having been calculated from the actual corrosion losses, assuming dry rust to contain 70% of iron.

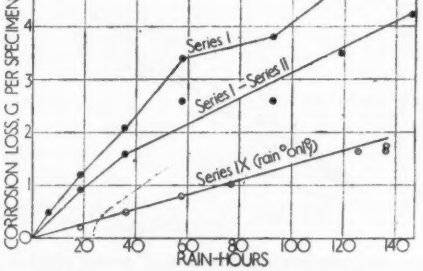

Fig. 3—Corrosion loss per rain-hour

The exposure to 65% relative humidity was continued for 83 days without any increase in weight being apparent.

Some later exposures to 100% relative humidity gave very erratic results, mostly 2–3 times higher than those plotted. It is thought that this was due to condensation of moisture, and therefore the results for this humidity should be taken with reserve.

The marked increase in rate of rusting in humidities higher than 80% is in accord with the work of Vernon[6] and of Schikorr.[5] The specimens previously rusted under shelter corroded much more rapidly than those previously rusted in the open, presumably on account of the thinner layer and greater sulphur content (*see* page 245) of the rust on the former.

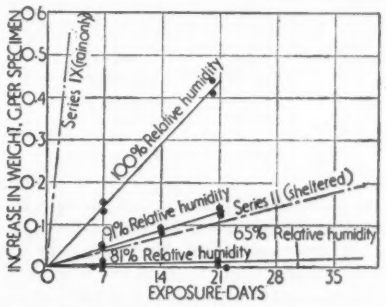

Fig. 4—Humidity corrosion; 4-in. sq. panel steel, previously rusted for 128 days in the open air

The average relative humidity to which the series II (sheltered) specimens had been exposed throughout the 2 years appears to have been in the region of 85–90%, by interpolation from Figs. 4 and 5.

An attempt was made to compute the number of hours per year during which the relative humidity ranges between certain values. This was done by interpolating from the isopleth diagrams published by the Meteorological Office,[7] from which the following data have been constructed showing the hours per year during which the mean hourly relative humidity was within the stated ranges :

Station	Period	Average Duration, hr./year Over 90% Relative Humidity	90–80% Relative Humidity	80–70% Relative Humidity	Under 70% Relative Humidity
Cranwell	1921–26	5100	1500	1600	560
Croydon	1920–26	2500	3900	860	1500
Renfrew	1920–26	1600	5000	1450	760
Leuchars	1921–26	1300	5200	2100	160
Sealand	1921–26	800	5600	1800	560
Kew	1886–1910	660	4600	1600	1900
Falmouth	1886–1910	560	5700	2500	0
Aberdeen	1886–1910	0	5090	3670	0
Valencia	1886–1910	0	7070	1690	0

The inland stations recorded longer periods of high and of low humidity than the coastal stations, chiefly because of greater temperature variations inland. There would thus appear to be more opportunity for condensation and humidity corrosion under an inland climate in Britain than at the coast.

Combining the data in Fig. 5 with average inland conditions given above, an attempt was made to

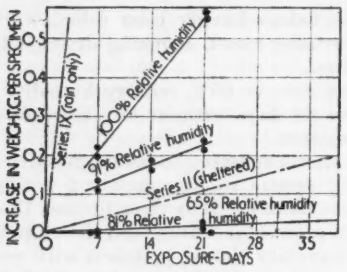

Fig. 5—Humidity corrosion; 4-in. sq. panel steel, previously rusted for 128 days under shelter

analyse the annual humidity corrosion, with the following results :

Humidity Range (i)	Hours per Year (ii)	Corrosion, g./hr. (from Fig. 5) (iii)	Corrosion per Year (ii × iii)
Over 90%	1300	0·00075	1·0
90–80%	4900	0·00030	1·45
80–70%	1850	0·00003	0·05
Under 70%	710	Nil	0·00
	8760		2·50 g. gain in wt.

A gain in weight of 2·5 g. on the specimens used is equivalent to a corrosion loss of 5·8 g., which is typical of the loss from the series II (sheltered) specimens during their first year's exposure.

The above analysis implies that 98% of the annual humidity corrosion occurs during 71% of the total time (80–100% humidity range), and that 40% occurs during 15% of the total time (90–100% humidity range), under average inland conditions in Britain. The distribution would be different under coastal conditions.

INFLUENCE OF ENVIRONMENT AND ASPECT

Figure 6 shows the corrosion losses on a time basis for series I, II, IV, V, and VI.

Series IV, exposed at 45° to the vertical, suffered 10–20% more loss than series I, which was exposed in a vertical position. Two specimens in series IV each had one surface protected with paint during the first years' exposure. These showed that 54% of the total loss occurred on the underside of these 45° specimens. Larrabee[8] gives 52·4% and 52·8% for 30° specimens exposed for nearly 4 years. A similar treatment of two series I specimens showed no difference in loss between the side facing the prevailing wind and the reverse.

The underside of the 45° specimens was always covered with a thick layer of flaky rust which contrasted with the thinner layer of hard compact and adherent rust formed on the upper side. As the underside was not exposed to direct rainfall, the increased corrosion loss on that side must have been due to the presence of the thick and flaky rust, as this would harbour moisture and so promote slow corrosion over a long period of time when the upper surface was comparatively dry. There is also some evidence that direct rainfall washes sulphur compounds from the upper surface, whereas these accumulate on the underside and accelerate corrosion there.

This experience with the 45° specimens provided a clue to the idea that direct rainfall is not the dominant cause of corrosion, and it led to the subsequent exposure of series IX only during rainfall, with results already mentioned.

The specimens exposed in a rural atmosphere near Derby (series V) suffered 75–80% of the loss suffered by the series I specimens exposed simultaneously in the industrial atmosphere outside the laboratory. This conforms with the results of many other workers and is a well-known feature of atmospheric corrosion.

INFLUENCE OF CONDITIONS AT START OF EXPOSURE

During the discussion of a paper by Schramm and Taylerson,[9] it was considered that the season when an atmospheric corrosion test was started might influence the subsequent corrosion rate (*i.e.*, tests started in a dry season might show less corrosion than those started in a wet season). With this in view, four series of specimens of panel steel *BWK* have been started at different seasons under the following conditions.

Series I—Exposure commenced 28th January, 1944. Weather : fine and dry. Four days elapsed before the first recordable rain fell, but rusting due to humidity was visible within the first 24 hr.

Series VI—Exposure commenced 12th June, 1944, with the object of securing summer conditions at the start, but rain fell on each of the first four days of exposure.

Series VII—Exposure commenced 7th December, 1944. Rain fell on that day, and on the third, fourth, and fifth days of exposure.

The corrosion losses of these three series have been plotted on a basis of exposure-days and of rain-hours for comparison. On both bases there is no appreciable difference between series I and series VI up to 2 years' exposure. The first having been started in a dry spell in the winter and the other during a wet spell in the summer, the desired conditions were not secured, and the result is inconclusive.

In order to overcome the vagaries of the weather at the start of the exposure, series III was started on 7th June, 1945. One-half of the specimens were given an emery finish 23 days earlier and stored at 65% relative humidity and 70° F. until exposed to the weather. The remaining specimens were given an emery finish immediately prior to exposure on 7th June, 1945. That day was fine and dry, but all specimens rusted slightly overnight owing to humidity. Rain fell on 8th June, 1945.

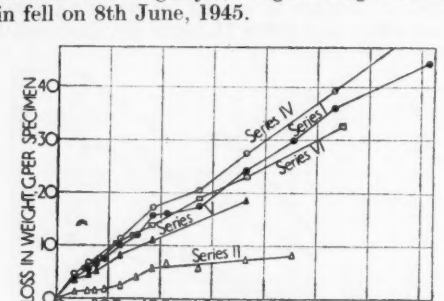

Fig. 6—Atmospheric corrosion of panel steel, 4 in. sq. × $\frac{1}{16}$ in., at Derby

The specimens removed after 6, 12, and 24 months' exposure had lost almost identical amounts through rusting; the 23 days' dry storage had induced no protection. The results were plotted on a rain-hours basis and followed very closely those of series I, VI, and VII.

It is concluded that, under the conditions obtaining outside the Derby laboratory, the weather prevailing at the start of a test has no significant effect on the subsequent corrosion rate.

SHEDDING OF RUST

Periodic examination of the specimens showed that those exposed to full weather conditions were liable to a flaking off of rust during the spring months. This process was followed in some detail by weighing specimens before as well as after de-rusting at the termination of their exposure, in order to obtain the weight of the adherent rust. Other specimens were weighed periodically during the course of their exposure and the rust weight was calculated after making an allowance for the loss in weight of the steel by corrosion.

These observations showed that the rust adhering to the specimens reached a maximum during February or March of 0·06–0·09 g./sq. cm. Shedding of the rust during spring reduced this to 0·03–0·04 g./sq. cm. during June or July, after which the rust gradually accumulated during the remaining eight months of the annual cycle. This feature was observed during four successive years, and specimens whose exposure had started at different seasons shed their rust simultaneously.

The specimens exposed at 45° (series IV) accumulated the greatest weight of rust, especially on the underside which was sheltered from the direct impact of rain drops. The sheltered specimens (series II) did not appear to shed their rust periodically and accumulated only 0·01–0·02 g./sq. cm. of rust which was very friable compared with the compact and adherent rust found on the open-air specimens.

EXPANSION EFFECTS DUE TO THE FORMATION OF RUST

Expansion due to the formation of rust may cause trouble in building construction where rusting of steel in some confined space may result in unexpected stresses. To obtain a rough measure of the lateral expansion due to rusting, and to study corrosion of semi-exposed steel, two piles of five 4 × 4-in. specimens of panel steel *BWK*, with a rough-emery finish, were placed on a horizontal surface on the laboratory roof, weighted by $3\frac{3}{4}$ and 14-lb. steel blocks, and the height of each pile noted at intervals. One plate was withdrawn from each pile after 6 months and another after 12 months for de-rusting and weighing. Allowance was made for these withdrawals when assessing the subsequent increase in height of the piles due to the rusting of the specimens.

On a basis of 10 rusting surfaces per pile at the start of the exposure, the expansion at the end of the first 12 months amounted to 0·023 in. per surface for the $3\frac{3}{4}$-lb. weight and 0·022 in. per surface for the 14-lb. weight. The expansion due to adherent rust on specimens exposed vertically to the weather during the same 12 months was one-tenth of this value owing to loss of rust by weathering.

The corrosion loss on these piles of plates was approximately one-half that of the specimens hung vertically in the open during the same 12 months. This was surprising, as the capillary effect of the interstices between the piled plates had been expected to promote a prolonged state of wetness on the corroding surfaces. Actually there were irregular areas entirely free from corrosion. This might be due to (*a*) good contact between the plates, (*b*) an air lock preventing access of water, or (*c*) cathodic protection by the surrounding rust (*see* U. R. Evans[10]).

SULPHUR CONTENT OF RUST

Rust was scraped from some of the specimens at the termination of their exposure and analysed for sulphur content. The results are given below and include rust taken from similar specimens exposed outside and inside certain tunnels on the Euston–Watford electric line; no steam trains use these tunnels:

Position of Exposure	Total Sulphur, %
Inside Kensal Green tunnel	2·75
Inside Primrose Hill tunnel	2·22
Derby : sheltered from rain, series II ...	1·7
Derby : underside of 45° specimen ...	1·4
Derby : fully exposed, series I	1·15
Outside Primrose Hill tunnel	1·13
Derby : upper surface of 45° specimen ...	1·1
Outside Kensal Green tunnel	0·97
Derby : fully exposed, series I	0·8
Derby : exposed only to rain, series IX ...	Trace

The highest sulphur contents occur in those specimens sheltered from rain, but exposed to humidity. The specimen exposed only to rain and protected from humidity corrosion contained but a trace of sulphur. Specimens exposed to all the elements contained an intermediate amount of sulphur. It is evident that one direct effect of rain is to wash out sulphur compounds which would otherwise stimulate corrosion.

COMPARISON WITH OTHER INVESTIGATIONS

Exposure tests were made by Britton[11] on 3 × 2 × $\frac{1}{16}$-in. specimens of panel steel (reference *AJV*), between April 1936 and February 1937. The emery-finished specimens were exposed on the roof of the Derby laboratory at 45° to the vertical, and the corrosion losses per unit area followed closely those of series I in the present tests.

The following figures are a comparison of the results of the present tests with those of the 4 × 2 × $\frac{1}{8}$-in. ingot-iron specimens exposed for one year by the Corrosion Committee[1] (*loc. cit.*, Table XXIII, p. 209F):

Corrosion Committee (Ingot Iron)	L.M.S.R. (Panel Steel)	Corrosion Loss, oz./sq. ft.
Llanwrtyd Wells (rural)		1·52
	Series V (rural)	1·70
Calshot (marine)		1·77
Motherwell (industrial)		2·37
	Series I (industrial)	2·40
Woolwich (industrial)		2·58
	Series IV (45°)	2·60
Sheffield (industrial)		3·35
Derby, south end (industrial)		3·50
Derby, north end (industrial)		3·63
Frodingham (industrial)		4·30

The experiments at Derby included the exposure of zinc control specimens, $4 \times 3\frac{1}{2} \times 0{\cdot}015$ in., and the losses from these are compared below with those from the $4 \times 2 \times 0{\cdot}05$-in. zinc control specimens exposed by the Corrosion Committee :

Corrosion Committee (Mean Values)	L.M.S.R., Derby	Corrosion Loss in 1 year, oz./sq. ft.
	Vertical (1945)	0·072
Llanwrtyd Wells		0·073
	45° (1945)	0·077
Calshot		0·080
Woolwich		0·089
	45° (1944)	0·091
	Vertical (1946)	0·092
	Vertical (1944)	0·093
	Vertical (1947)	0·100
Motherwell		0·103
Derby, south end		0·170
Derby, north end		0·195
Frodingham		0·244
Sheffield		0·405

The zinc control specimens exposed with series II (sheltered) gained in weight by 0·029 oz./sq. ft. during the year owing to lack of rain to remove the corrosion products.

The foregoing figures show that the atmosphere prevailing outside Derby laboratory decreased in corrosiveness from the time of the Corrosion Committee's tests (1941–43) to that of the present tests (1944–47). This may be due to the fuel shortage during the latter years. The low losses at Derby during 1945 may be connected with the reduced rain-hours of that year (332 compared with 452 for 1944 and 527 for 1946), since zinc produces a non-adherent corrosion product which is washed off by the rain.

Compared with other exposure stations, the conditions outside Derby laboratory during these tests can be described as moderately industrial.

CONCLUSIONS

(*a*) Atmospheric corrosion of steel is not directly related to rainfall. In the industrial atmosphere of Derby, only 35–40% of the total corrosion occurred during the hours when the rainfall was sufficient to register on a recording gauge. A further 35–40% was due to the effects of humidity, and the balance is presumed to have occurred during periods of drizzle and dew and when the specimens remained wet after recordable rainfall had ceased.

(*b*) Measurements of corrosion rate of previously rusted specimens under controlled humidities showed a marked increase in the rate when the relative humidity was above 80%. A computation of the hours during which certain ranges of humidity might be expected under inland conditions in Britain led to the conclusion that 40% of the annual humidity corrosion occurs in the 90–100% humidity range and this prevails for about 15% of the year.

(*c*) An estimate of the causes of corrosion of steel during the first year under industrial conditions at Derby shows the following distribution :

	Annual Loss g. per specimen	%
Recordable rain, 400 hr. at 0·014 g./hr.	5·6	38
Drizzle Drying periods Effect of sulphur } By difference ...	3·4	23
Humidity :		
Over 90%, 1300 hr. at 0·0017 g./hr.	2·2	15
90–80%, 4900 hr. at 0·0007 g./hr. ...	3·43	23
80–70%, 1850 hr. at 0·00007 g./hr.	0·13	1
Under 70%, 710 hr. at nil g./hr. ...	...	...
	14·76	100

(*d*) Corrosion was slightly greater on the undersides than on the upper surfaces of specimens exposed at 45°, showing that direct rainfall was not the dominant factor causing corrosion.

(*e*) Corrosion in a rural atmosphere outside Derby was 75–80% of that in an industrial atmosphere in Derby.

(*f*) No connection could be established between the weather prevailing at the start of exposure and the subsequent corrosion rate.

(*g*) An annual cycle of rust-shedding was noticed. The rust adhering to the specimens attained a maximum of 0·06–0·09 g./sq. cm. during February or March. Flaking off then reduced this to 0·03–0·04 g./sq. cm. during June or July.

(*h*) The expansion due to rusting of a pile of exposed plates amounted to 0·045 in. per plate during the first year.

(*i*) The sulphur content of rust formed under industrial conditions was found to be of the order of 2% when sheltered from rain, and about 1% where exposed to rain. Exposure to rain only and protection from humidity corrosion resulted in a mere trace of sulphur in the rust.

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Cast Crankshafts

A SURVEY OF PUBLISHED INFORMATION

By R. J. Love

SYNOPSIS

A detailed survey is made of published information on the subject of cast crankshafts and the following aspects are discussed: (1) The behaviour of cast crankshafts in service and the influence of the various material properties, (2) cast materials, surface treatments, and special heat-treatments, (3) features of design, and (4) the advantages of using cast crankshafts. Reference is also made to sources of information concerning the production of cast crankshafts.

The results of various tests on cast crankshafts and on the more conventional forged crankshafts are given and indicate that cast crankshafts normally have lower bending fatigue strengths than forged shafts, the materials used for forged crankshafts having, in general, considerably greater tensile strengths than the cast materials. The torsional fatigue strengths of cast shafts compare more favourably with those of forged crankshafts, but are lower than those of forged crankshafts of high tensile strength. Nevertheless, cast crankshafts are seen to have a very good record for behaviour in service.

The various points concerning the advantages of using cast crankshafts can be summarized in the statement that the casting process provides a means of quickly and cheaply supplying a crankshaft of very high wear resistance and of the most desirable shape, this shape being such as to impart to the engine certain favourable characteristics which could not be obtained in the forged shaft except at high cost.

Introduction

THE cast crankshaft has been shown to give satisfactory service behaviour and has for some time promoted interest among engine builders and engine users. In view of this it has been considered desirable to write a survey of the published information on the subject, thus making available to those interested as much data as possible concerning all the various features of the use of the component. The considerable amount of information contained in the literature has been arranged, and in most cases discussed, under the following headings:

(1) Behaviour of cast crankshafts in service.
(2) Mechanical properties of the crankshaft material.
(3) Advantages of using cast crankshafts.
(4) Cast crankshaft materials.
(5) Design of cast crankshafts.
(6) Production of cast crankshafts.
(7) Special processes.

It will be seen that the cast crankshaft has been made in considerable quantities, with various cast materials, and in a very wide range of sizes, and that it has been employed in oil, petrol, and gas engines, and in compressors and locomotives.

In the automobile field, the Ford Motor Company appears to have been the first to use the cast crankshaft in standard production. In this case mass-production methods have been employed, and at one time cast shafts were being produced at the rate of 6500 per day.[1]

Most of the larger cast crankshafts, weighing 10,000 lb. or more,[2] have been made in America, and the chief user appears to be the United States Navy, employing engines with crankshafts of nine or ten throws and 8-in. dia. main journals.[3] A cast crankshaft 8 ft. 9 in. long with 9½-in. dia. main journals has also been successfully developed.[4] In this country, the largest cast crankshaft produced was a five-throw shaft with a main journal diameter of 8 in.* In Germany, a three-throw cast crankshaft 12 ft. long having journals of approximately 9 in. dia. was used in a high-pressure pump for providing pressures of up to 300 atm.[6]

Cornelius and Bollenrath[7] and Roll[8] point out that cast crankshafts were in existence during the last century, and the use of some cast steel crankshafts in locomotives in 1894 and in 1926 has been referred to by Hughes[9] and Krieger,[10] respectively. However, the recent trend towards the use of the cast crankshaft, made possible by the development of cast materials of considerable strength,[11, 12] appears to have been initiated about 1929, in America. After a period of five years or so, during which time careful observation was made of the behaviour in service of a great number of cast shafts, the new component was placed on a production basis. In 1932 several American manufacturers were developing cast crankshafts,[4, 14, 15] and in this country one firm started developing cast crankshafts at about the same time; by 1934 this firm had supplied a large number of cast steel crankshafts which had proved very successful.[16] The German motor industry was said to have been experimenting with cast crankshafts in 1935.[17]

BEHAVIOUR OF CAST CRANKSHAFTS IN SERVICE

Details of the service behaviour of cast crankshafts are of foremost interest. It is only with the knowledge that a cast crankshaft is likely to perform its job

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* Information given by Mr. R. B. Templeton at a meeting of the Institution of Automobile Engineers previous to the reading of his paper entitled "The Production of Cast Crankshafts" (reference 5).

satisfactorily that the engine designer will look further into the question of the possible advantages or disadvantages accruing from its use. Very favourable accounts of the component are available from various sources.

Dwyer,[13] writing in 1934, reports that approximately 2000 cast crankshafts had been placed in one make of car where their behaviour could be checked closely, and after a period of about two years none of these shafts had failed in service or shown distortion or appreciable wear. He considers that the cast crankshaft is superior in practically every respect to the forged shafts formerly used. Walls,[18] writing of the same crankshaft in 1937, records that up to that time between two and three million cast crankshafts had gone into service, with a marked reduction of failures below the number encountered in forgings. Templeton[5] claims to have been associated with the manufacture of over 50,000 cast crankshafts covering over a hundred different types and sizes, and states that failures in service from all causes, *i.e.*, poor design, faulty material, etc., have been below 0·1%. Bergdoll[19] writes of crankshafts of special cast iron, used in compressors of various sizes made in the United States and points out that in over three years of use not one of the crankshafts had failed, although thousands were in operation.

West[20] refers to an experimental cast iron crankshaft being fitted to a four-cylinder petrol engine which developed 74 h.p. at 2500 r.p.m. This crankshaft ran satisfactorily for the complete trial period of 2½ years. Later, shafts of the same material were fitted in two six-cylinder compression-ignition engines run in public service vehicles, but both of these shafts broke after the short period of three months. It should be noted, however, that the iron used for these shafts had a bending fatigue strength of 7·5 tons/sq. in., which is lower than that of most of the cast materials which have been used.

An American firm has carried out several tests using special-iron crankshafts.[4] First, cast crankshafts were made for 12 two-cylinder gas engines with crankpins and main journals of 4½ in. dia.; the peak bending crankpin stress was calculated at 7050 lb./sq. in. These engines were placed in service and none failed. Later, 210 engines with journals of 3¾ in. dia. and operating at a crankpin stress of 6180 lb./sq. in. were placed in service; none of these cast crankshafts failed. A gas Diesel cast crankshaft 8 ft. 9 in. long and with crankpin and main journals of 9½ in. dia. was then operated at a crankpin stress of 6220 lb./sq. in. for 40 million cycles with a purposely high peak pressure. During this experiment two pistons seized, but the crankshaft was unimpaired. A 5½-in. dia. crankshaft was operated successfully in a single-cylinder test unit for 20 million cycles at 900 lb./sq. in. peak pressure. Finally, a " test to end all tests " was carried out. A Diesel engine having a six-throw crankshaft 7 ft. 8 in. long with crankpins of 5⅝ in. dia. was operated at a peak pressure of 900 lb./sq. in. for 20 million cycles; during the test a bearing ran out of line and caused a big crankshaft deflection, but this did not damage the crankshaft. The peak pressure was then increased to 1000 lb./sq. in. for 20 million cycles, but again no damage resulted. Finally the engine was operated at a critical speed, causing a very large crankshaft vibration. The crankshaft cracked, but was run for a further 12 hr., after which the crack had progressed halfway through the section; in spite of this the engine was still running satisfactorily. Four of these five types of special-cast iron shafts replaced 0·45% carbon, 36 tons/sq. in., steel shafts without any change of crankpin diameter, main journal diameter, or thickness of crankwebs.

Templeton[5] refers to an engine test in which a cast crankshaft was subjected to an overload of 50% increase in piston loading. After the test period of 13 million cycles the crankshaft was in excellent condition and showed no excessive wear.

These various reports clearly show the possibilities of the cast crankshaft, and since the use of cast crankshafts in the high-duty cast irons is comparatively new it can be expected that future design, based on the results of research and the early experiences with cast crankshafts, will lead to an even greater measure of success.

MECHANICAL PROPERTIES OF THE CRANKSHAFT MATERIAL

A discussion of the advantages and disadvantages arising from the use of cast crankshafts in place of the more conventional forged crankshafts is clearly of primary importance, but since these advantages and disadvantages are related to matters of production and service behavour of the finished shaft, and, furthermore, since the service behaviour of the crankshaft is governed by the mechanical properties of the crankshaft material, it would appear to be desirable first to discuss these mechanical properties.

The various mechanical properties will be discussed individually and in each case two factors will be considered, namely, (i) the importance of the particular mechanical property in relation to service behaviour of the crankshaft, and (ii) the numerical value of the particular mechanical property in the case of cast crankshaft materials.

It appears to be necessary to introduce one other stage into the discussion. Before going on to discuss the mechanical properties, some consideration will be given to the different types of load imposed on the crankshaft in the engine.

CRANKSHAFT LOADS

In service the crankshaft is subjected both to torsional and bending loads. The torsional loads consist of two quantities, namely, the torque transmitted by the engine and alternating torque arising from torsional vibration set up in the crankshaft. The magnitude of these torsional vibrations usually varies considerably with engine running speed, and at certain running speeds, termed " critical speeds," may reach remarkable proportions.

In bending, loads are similarly derived from gaseous and inertia forces, and possibly from bending vibrations, but the problem of bending vibration does not seem to have received very much attention.[21–24]

Reference is also made to a third type of crankshaft vibration, namely, axial vibration. In this condition a crankshaft alternately decreases and increases in length. This vibration, which is sometimes said to

be associated with torsional vibration,[25–27] will of course result in a bending of the crankshaft webs.

Of the different types of crankshaft loading, torsional vibration has received the most attention,[28–31] and this type of loading is particularly important in certain engines. In other engines, crankshaft bending strength may be of prime importance. For example, bending strength is very important in the case of automobile crankshafts in which two or three main journals are used in conjunction with several cranks.[29, 32, 33]

From the foregoing it is clear that in engine design steps must be taken to reduce all vibration to a minimum. Apart from endangering crankshaft life, vibration may cause considerable wear on gears and auxiliary drives.[26, 30, 34] At the same time the crankshaft must have sufficient fatigue strength in bending and torsion, and conditions should be such as to provide for long life of journals and mating bearings. Finally, these requirements must be attained with a minimum of crankshaft weight and with a minimum cost of production.

Such characteristics of the finished crankshaft are governed by the properties of the crankshaft material, together with the crankshaft design.

FATIGUE STRENGTH AND NOTCH SENSITIVITY

It seems logical to assume that the bending fatigue strength of the crankshaft is closely related to the bending fatigue strength of the crankshaft material, a value which is usually determined by subjecting plain bars of the material to a rotating-beam fatigue test. In addition, since the shape of the crankshaft is such as to involve fairly sharp corners, it would appear that the bending fatigue strength of the crankshaft is also connected with the notch sensitivity factor for the crankshaft material, a factor which indicates the extent to which the fatigue strength of the material is reduced by the presence of a sharp notch and which is determined by comparing the rotating-beam fatigue strength of a plain bar with that of a bar carrying a sharp circumferential notch. Similarly, it would seem that the torsional fatigue strength of the crankshaft is governed by the torsional fatigue strength of the crankshaft material and the notch sensitivity factor for torsion, the "notched" torsional specimen usually consisting of a bar traversed by a small hole, similar to the oil hole in a crankshaft journal.

Many authors stress the importance of low notch sensitivity in a crankshaft material and, since cast iron has a low notch sensitivity, point to the possibility of using this material for crankshafts, in spite of its low tensile strength; forged steel and cast iron are compared, as crankshaft materials, by comparing their notched-bar fatigue strengths. The validity of this method will be discussed later.

Comparisons of some values for the fatigue properties of cast materials and of the more conventional crankshaft material, steel, follow.

Steel

The fatigue strength of a material is often conveniently expressed by means of the endurance ratio, which is the ratio of the limiting bending fatigue stress for the material to the tensile strength. For rolled steels this endurance ratio is usually found to be of the order of 0·5, although with the steels of higher tensile strength the average values for endurance ratio tend to drop below this figure[35] (*loc. cit.*, p. 77).

Matthaes[36] gives details of the mechanical properties of 14 crankshaft steels. The endurance ratios for these range from 0·43 to 0·55, the average being 0·49. A few values of the ratio of the torsional fatigue strength to the bending fatigue strength give an average of 0·65. This latter ratio is usually found to be from 0·50 to 0·60.

The effect of notches on the fatigue strength of steel varies with the steel and type of notch[35] (*loc. cit.*, p. 77), but the effect tends to be more pronounced with the steels of higher tensile strength.

The values given by Matthaes, together with the results of other bending and torsional tests,[37–39] suggest that crankshaft steels will have, very approximately, endurance ratios of 0·5, torsional to bending fatigue strength ratios of 0·6, notched bending fatigue strength reductions of 50%, and notched torsional fatigue strength reductions, owing to transverse holes, of 40%.

Cast Materials

Donaldson[40, 41] reviews the work of various investigators in connection with the bending fatigue properties of cast iron and records the various fatigue-test results. For 42 endurance ratios given for the various irons a range of 0·30–0·66 is covered, with a mean value of 0·47. Some values given by Donaldson have been excluded, as they appear to be very exceptional. For example, Gough and Pollard[42] found an endurance ratio of 1·00 for a high-silicon iron, and values of 0·815 and 0·68 were found by Pfannenschmidt. A low value of 0·19–0·26 was obtained by West. Tensile-strength figures are not given for all of the irons referred to by Donaldson, but those that are given cover a range of 9·3–25 tons/sq. in.

Donaldson concludes that cast iron has a relatively high endurance limit when compared with other metals and alloys; from the few results given in respect of notching he concludes that the notch effect is very much less than is obtained for most other materials but that high-duty irons show the notch effect to a much greater extent than the medium- and low-quality irons.

Mailänder[43] also reviews the work of several investigators and gives some of his own test results. In the case of two irons with tensile strengths of 13 and 17 tons/sq. in., respectively, no reduction of bending fatigue strength was found owing to notching, while a centrifugally cast material of 29 tons/sq. in. tensile strength suffered an 11% reduction of strength owing to the presence of a notch, and a 28 tons/sq. in. cast steel suffered a 33% reduction.

Mailänder shows that for a number of irons of strength up to 34 tons/sq. in. the torsional-fatigue-strength/bending-fatigue-strength ratio ranged from 0·75 to 0·95, with a mean of about 0·87. For some cast steels this ratio covered a range of 0·61–0·74.

Cornelius[37] has conducted fatigue tests on various cast crankshaft materials. Reversed bending tests were carried out on flat strips of the material in the

Table I

CHEMICAL ANALYSES OF CAST MATERIALS USED BY CORNELIUS (REFERENCE 37)

	Malleable Iron			Ni–Mo Cast Iron			High-Carbon Cast Steel	
	(*a*)	(*b*)	(*c*)	(*a*)	(*b*)	(*c*)	(*a*)	(*b*)
Carbon, %	1·90	1·62	1·94	2·86	2·27	2·61	1·49	1·28
Silicon, %	0·84	1·00	0·98	1·48	1·62	2·16	0·99	1·44
Manganese, %	0·25	0·21	0·24	0·71	0·47	0·68	0·48	0·78
Sulphur, %	0·056	0·070	0·054	0·074	0·061	0·057	0·027	0·021
Phosphorus, %	0·059	0·060	0·068	0·098	0·091	0·077	0·048	0·027
Nickel, %	Trace	Trace	Trace	1·22	1·37	1·37	...	0·08
Chromium, %	Trace	Trace	Trace	...	...	...	0·55	0·16
Molybdenum, %	Trace	Trace	Trace	0·74	0·70	1·15	...	Trace
Copper, %	0·05	0·04	0·05	...	...	...	1·48	0·07
Aluminium, %	0·03	0·03	0·06	...	...	...	...	0·03
Titanium, %	0·02	0·03	0·03	...	...	...	...	0·01

notched and unnotched conditions, and alternating torsion tests were carried out on notched and unnotched bars, the notched torsional specimen consisting of a bar traversed by a small hole. In addition, a few alternating torsion tests were carried out using hollow bars traversed by small holes. The materials tested were (1) three malleable irons, (2) three nickel–molybdenum cast irons, and (3) two alloyed, high-carbon cast steels. The chemical compositions of these materials are given in Table I, while the fatigue-test results, tensile strengths, and Brinell hardness numbers are given in Table II. For the purpose of comparison Table II also gives some torsional fatigue values obtained for two rolled steels, each of these steels being tested in two conditions of heat-treatment. Cornelius gives also some bending fatigue results for rolled steels, but these are not strictly comparable with the results from the cast materials, as the test-specimens in the two cases were of different form. However, the bending fatigue endurance ratios for these steels covered the range 0·48–0·56. Cornelius discusses his test results fully, making reference to the results obtained by several other investigators.

Collins and Smith[44] have carried out static and fatigue tests on four cast irons. These irons are not described as crankshaft irons by the authors but, as they point out, the fatigue-test results on irons of this kind are of interest in connection with materials for cast crankshafts, among other things. The materials tested covered a wide range of chemical composition, the four irons being (1) a slightly alloyed ordinary grey cast iron, (2) a high-strength nickel–molybdenum iron, (3) a slightly alloyed nickel–chromium–copper inoculated iron, and (4) a high-nickel–copper–chromium iron of the austenitic type. The chemical compositions of the irons tested are given in Table III and fatigue-test results are given in Table IV. For both the bending and torsional fatigue tests the notched specimens consisted of a round bar with a transverse hole.

Table II

MECHANICAL PROPERTIES OF MATERIALS TESTED BY CORNELIUS (REFERENCE 37)

	Malleable Irons			Ni–Mo Irons			High-Carbon Cast Steel		Ni–Cr–W Rolled Steel		Ni–Cr–Mo–V Rolled Steel	
	(*a*)	(*b*)	(*c*)	(*a*)	(*b*)	(*c*)	(*a*)	(*b*)	(i)	(ii)	(i)	(ii)
Tensile strength, tons/sq. in.	19·4	19·7	20·3	21·5	23·0	27·5	41·3	46·4	60·3	82·5	62·6	82·5
Brinell hardness number	128	108	...	243	280	290	236	246	270	368	280	370
Bending fatigue strength:												
Unnotched, tons/sq. in.	...	9·8	9·1	9·7	7·6	13·8	9·7	9·3	...	...	...	...
Notched, tons/sq. in.	...	6·1	6·4	7·1	6·2	9·5	9·5	9·0	...	...	...	...
Bending endurance ratio	...	0·50	0·45	0·45	0·33	0·50	0·23	0·20	...	...	...	...
Reduction of bending strength due to notch, %	...	38	30	27	18	31	1	4	...	...	...	...
Torsional fatigue strength:												
Unnotched, tons/sq. in.	8·2	...	7·6	10·0	9·5	12·9	11·4	10·8	16·5	20·6	18·7	19·0
Notched, tons/sq. in.	6·0	...	5·4	7·5	6·9	9·1	6·1	8·8	11·1	13·7	12·1	14·0
Torsional endurance ratio	0·42	...	0·38	0·47	0·41	0·47	0·28	0·23	0·27	0·25	0·30	0·23
Reduction of torsional strength due to notch, %	27	...	29	25	27	30	47	18	33	34	36	27
Torsional fatigue strength of hollow notched specimens, tons/sq. in.	...	...	4·8	6·4	4·7	8·4	...	...	...	...	...	...
Torsional - fatigue - strength/bending - fatigue - strength ratio	...	...	0·84	1·03	1·25	0·95	1·18	1·16	...	...	...	...

Gough and Pollard[12] have carried out fatigue tests on five cast crankshaft materials, using the rotating-beam bending test, the torsional fatigue test, and fatigue tests involving various conditions of combined bending and twisting, with the aid of a special machine. The materials investigated were (1) a cast alloy steel, (2) a copper–chromium iron, (3) an inoculated iron, (4) a chromium–molybdenum iron, and (5) a nickel–chromium iron. Notched specimens were tested only in the case of the cast alloy steel. Details of the alloys tested, including chemical analyses, are given in Table V, and the various mechanical properties, including the rotating-bending and alternating-torsion test results, are given in Table VI. A sharp circumferential notch reduced the bending fatigue strength of the specimens of the alloy steel by 35% and reduced the torsional strength by 26%.

The combined stress fatigue tests carried out by Gough and Pollard are probably of great interest in connection with the study of fatigue phenomena, but it is difficult at present to assess their value in relation to the question of materials for crankshafts. As pointed out by Gough and Pollard, the crankshaft is subjected in service to combinations of static and cyclic bending and torsional moments, but unknown conditions are, firstly, the order of magnitude and sequence of these different loads in a crankshaft system, and, secondly, the different combinations of stress produced by these loads at particular locations in the crankshaft. If it were possible to determine the conditions of stress, in service, at any point in the crankshaft, or at least at the " critical " points, it might then be possible to predict the life expectancy of the crankshaft by reference to combined stress fatigue results for the crankshaft material. The positions of maximum stress in the crankshaft resulting from a bending load do not necessarily coincide with the positions of maximum stress resulting from a torsional load,[45] so that danger of failure in bending would probably not be increased greatly by torsional loads even if the peak torsional loads occurred at the same time as the peak bending loads. Similarly, torsional failure would not be dependent to any great extent on bending loads. In an investigation of crankshaft strength it seems sufficient to determine quite separately the bending fatigue strength of the crankshaft and the torsional fatigue strength of the crankshaft.

Table III

CHEMICAL ANALYSES OF CAST MATERIALS TESTED BY COLLINS AND SMITH (REFERENCE 44)

	Ordinary Grey Iron	Ni–Mo Iron	Ni–Cr–Cu Inoculated Iron	High-Ni–Cu–Cr Iron
Carbon, %	3·22	3·11	2·84	2·63
Silicon, %	1·75	2·23	1·52	2·14
Manganese, %	0·51	0·66	1·05	1·23
Sulphur, %	0·138	0·104	0·124	0·065
Phosphorus, %	0·48	0·10	0·07	0·16
Nickel, %	0·04	1·49	0·20	14·90
Chromium, %	0·01	0·09	0·31	2·09
Molybdenum, %	...	0·79	...	...
Copper, %	0·05	0·18	0·37	6·94
Titanium, %	...	0·025	0·020	0·022
Vanadium, %	...	0·010	0·005	0·005
Arsenic, %	...	0·021	0·013	0·012

It may quite well be, however, that under conditions of " pure bending " the critical location in a crankshaft—a very irregularly shaped body—may be subjected to transverse stress and shear stress in addition to the greater longitudinal tensile stress, thus introducing combined stresses. However, the nature of such combined stresses cannot be determined by the designer, and therefore the combined stress fatigue tests cannot be used in the estimation of crankshaft bending fatigue strength. The same applies, of course, to crankshaft torsional loading.

It seems most desirable, at present, to attempt to establish relationships between crankshaft bending fatigue strength and bending fatigue values obtained on simple test-specimens of the crankshaft material and between crankshaft torsional fatigue strength and torsional fatigue values obtained on simple test-specimens. If it so happens that crankshaft bending fatigue strength and torsional fatigue strength can be reliably related to the tensile strength of the crankshaft material, accurate crankshaft design will clearly be even more easy to achieve.

Comparison of Cast Materials and Steel

A nickel–chromium steel of, say, 60 tons/sq. in. tensile strength would have a notched bending fatigue

Table IV

MECHANICAL PROPERTIES OF MATERIALS TESTED BY COLLINS AND SMITH (REFERENCE 44)

	Ordinary Grey Iron	Ni–Mo Iron	Ni–Cr–Cu Inoculated Iron	High-Ni–Cu–Cr Iron
Tensile strength, tons/sq. in.	9·9	23·8	20·5	14·1
Bending fatigue strength:				
Unnotched, tons/sq. in.	4·0	9·4	9·0	5·4
Notched, tons/sq. in.	3·6	6·3	7·6	3·1
Bending endurance ratio	0·38	0·39	0·44	0·38
Reduction of bending strength due to notch, %	11	33	15	42
Torsional fatigue strength:				
Unnotched, tons/sq. in.	4·9	9·8	7·6	5·4
Notched, tons/sq. in.	3·6	7·1	6·4	4·5
Torsional endurance ratio	0·5	0·41	0·37	0·38
Reduction of torsional strength due to notch, %	27	27	16	17
Torsional-fatigue-strength/bending-fatigue-strength ratio	1·22	1·05	0·85	1·00

strength of about 15 tons/sq. in. and a notched torsional fatigue strength of about 11 tons/sq. in. If the crankshaft materials be considered on the basis of notched bending fatigue strength, the nickel–chromium steel would be superior to the cast irons referred to in Tables II and IV, the highest value for notched bending fatigue strength shown being 9·5 tons/sq. in. (Table II). Similarly, the nickel–chromium steel would be superior to the cast irons in torsional strength, but in this case the difference is not so great. The copper–chromium iron referred to in Table VI has an unnotched torsional fatigue strength of 13·9–14·7 tons/sq. in., but, unfortunately, notched tests were not carried out on this iron. If, however, one assumes a torsional strength reduction of say 27% owing to notching—a normal value according to Tables II and IV—a notched strength of 10·5 tons/sq in. is obtained, and this value is not very far different from that of the nickel–chromium steel.

A 35 tons/sq. in. medium-carbon steel, which is frequently used for crankshafts in the larger engines, would have a notched bending fatigue strength of about 8·5 tons/sq. in. and a notched torsional fatigue

Table V

CHEMICAL ANALYSES AND CONDITION OF MATERIALS TESTED BY GOUGH AND POLLARD (REFERENCE 12)

Material	Condition	Chemical Composition							
		C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Mo, %	Cu, %
Alloy steel	The billet, as cast, was annealed at 860° C. The individual test-pieces cut from this billet were oil quenched from 850° C. and tempered at 650° C.	0·32	0·23	0·88	0·040	0·030	2·42	0·49	0·38	0·13
Copper–chromium iron	Heated to 900° C., held for 20 min., cooled in air to 650° C.; reheated to 760° C., held for 60 min., cooled in furnace to 540° C. in 60 min.; cooled in air	1·56	1·16	0·44	0·049	0·067	Trace	0·46	...	1·57
Inoculated iron	As cast	2·75	1·59	0·88	0·073	0·076	...	...	0·29	...
Chromium–molybdenum iron	As cast	3·28	2·19	0·95	0·095	0·170	...	0·42	0·95	...
Nickel–chrome iron	As cast	3·36	1·22	0·92	0·113	0·124	1·87	0·47	...	...

Table VI

MECHANICAL PROPERTIES OF CAST MATERIALS TESTED BY GOUGH AND POLLARD (REFERENCE 12)

	Alloy Steel	Cu–Cr Iron	Inoculated Iron	Cr–Mo Iron	Ni–Cr Iron
Tensile strength, tons/sq. in.	52·3	32·3	23·3	20·8	18·8
Modulus of elasticity, lb./sq. in., $+10^{-6}$	29·3	26·8	21·7	20·1	18·7
Torsional modulus of rupture, tons/sq. in.	46·5	38·6	31·9	32·7	21·1
Modulus of rigidity, lb./sq. in., $+10^{-6}$	11·5	11·4	8·6	8·6	7·1
Brinell hardness number	260	260	245	280	265
Izod notched-bar value, ft.lb.	24·8	1·2	1·5	0·8	0·4
Alternating bending fatigue strength, tons/sq. in.	±22·3	±21–±19	±12·9	± 9·4	± 8·9
Alternating bending endurance ratio	0·43	0·65–0·59	0·55	0·45	0·47
Alternating torsional fatigue strength, tons/sq. in.	±14–±12·3	±14·7–±13·9	± 9·7	± 8·4	$\leqslant$± 7·1
Alternating torsional endurance ratio	0·27–0·24	0·46–0·43	0·42	0·40	$\leqslant$ 0·38
Torsional - fatigue - strength / bending-fatigue-strength ratio	0·63–0·55	0·77–0·66	0·75	0·89	$\leqslant$ 0·80

strength of about 6·5 tons/sq. in. These values can be matched and improved upon in some cases by the irons and cast steels referred to in Tables II and IV, this being especially so for torsion.

If the various materials are considered on the basis of unnotched fatigue strength, the cast materials are in a less favourable position to compete with the nickel–chromium and medium-carbon steels. On this basis the nickel–chromium steel is considerably superior to the cast materials, but the medium-carbon rolled steel is still weaker in bending than the cast alloy steel and copper–chromium iron of Table VI, and in torsion is weaker than five of the cast materials referred to in Tables II, IV, and VI.

The Importance of Notched Fatigue Strength

The difficulty of estimating the importance of notch sensitivity in the design of a component is increased by the fact that any one material has no fixed or basic index of notch sensitivity. The reduction of strength associated with the presence of a notch may alter considerably with the form and size of the notch, and, in addition, with the size of the notched bar. At the moment there are no standard dimensions for notched test-bars, and the notched tests have been carried out using a variety of shapes and sizes of specimen. Furthermore, Thum and Bautz[46] and Mickel[47] point out that the strength of a component is dependent on both the shape of the component and the material used. Apart from basic properties, determined by tensile tests or simple fatigue tests, a material has "form strength" properties, which refer to the behaviour of the material when used in particular shapes. The form strength properties may vary considerably from one material to another, and because of this the use of the simple basic properties of the material without reference to form strength, for assessing the strength of a part, brings successful results only in the case of components of simple shape. Thum and Bautz, and Mickel, stress the importance of carrying out tests on full-scale components in order to get a better understanding of form strength and so supply the designer with reliable data upon which he can base his calculations.

Mickel[47] has carried out some very interesting tests on small crank test-pieces of steel and cast iron. The

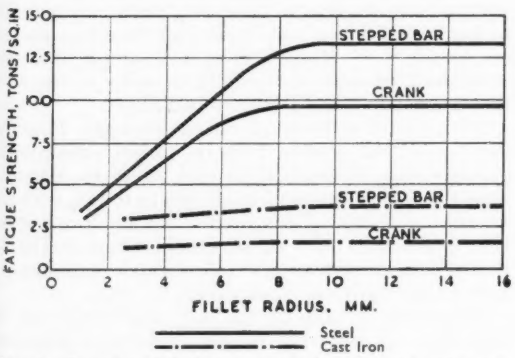


Fig. 1—Torsional fatigue strengths of steel and cast iron cranks and steel and cast iron stepped bars (Mickel)

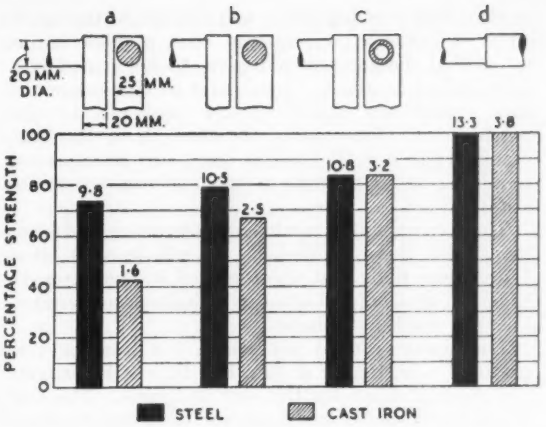


Fig. 2—Change of torsional fatigue strength (tons per square inch) with shape of crank (Mickel)

crank form is shown in diagram *a* of Fig. 2. The steel used had a tensile strength of 40 tons/sq. in., while the iron had a tensile strength of 10 tons/sq. in. The variation of the torsional fatigue strengths of the steel and cast iron cranks with the fillet radius is shown in Fig. 1, which also shows how the torsional fatigue strengths of stepped bars of the steel and cast iron vary with the size of the fillet joining the two sections of the bar.

The strengths of the steel stepped bar and steel crank are seen to increase considerably with increase of fillet radius, but the cast iron stepped bar and crank do not show a very marked increase of strength with fillet radius, and in addition the difference between the fatigue strengths of the cast iron stepped bar and crank is relatively much greater than for the steel.

Mickel considers that, having increased the fatigue strength of the crank element as much as possible by increasing fillet size, it might be possible, by careful design, to improve the limiting stress of the crank element further, until it approaches the value obtained with the stepped bar; he sets out to do this, and Fig. 2 shows how the strength of the steel and cast iron cranks are affected by changes in the shape of the crank, the strengths in each case being expressed as a percentage of the respective stepped-bar strengths. It is seen that the steel crank is not greatly affected by changes of shape, but the opposite applies to the cast iron crank. Mickel concludes that in the crank there is a "shape effect" and a "notch effect." The notch effect makes itself felt in the steel crank, as shown by the dependence of the steel-crank strength on fillet radius, while in the cast iron crank this effect is not important. On the other hand the shape effect is not felt very much by the steel, but is important in the case of the cast iron, as shown by Fig. 2.

The results of Fig. 2 would suggest that to attain high strength the cast crank must be carefully shaped, whereas the steel crank attains high strength, compared to the stepped-bar strength, without much attention being given to shape, a big advantage for the steel crankshaft. It must be remembered, however, that to investigate the shape effect Mickel used

models with very big fillets, and eliminated the notch effect, whereas a conventional ratio of fillet radius to journal diameter would give Mickel's models a fillet radius of about 1 mm., and in this range the steel cranks are clearly greatly weakened by the notch effect. Presumably the strength of the cast crank at this low fillet radius could still be improved in relation to the strength of the steel crank by careful shaping.

The experimental results of Lürenbaum[48] do not agree with those of Mickel. As will be seen later, Lürenbaum finds that the torsional fatigue strength of forged steel crankshafts can be influenced considerably by crankshaft shape.

Lürenbaum carried out also a few tests on cast shafts of a particular design, but did not investigate the effect of shape for the cast materials. The cast shafts were considerably weaker than the similarly shaped forged shaft, as will be seen later (Table XI). He considers that, because of the low sensitivity of the cast iron to notching, improvement in the strength of cast shafts by careful shaping cannot be expected. This would appear to be true if the crankshaft can be considered simply as a big notched bar, as is done by some authors ; attention to notch shape and size produces a change of fatigue strength of the notched bar only in the case of materials of high notch sensitivity.

A true estimation of the relation between the basic fatigue properties of a crankshaft material and the fatigue strength of the full-scale component can be achieved only after a lengthy series of fatigue tests on crankshafts of different materials and on simple fatigue specimens of those materials. So far, such a series of fatigue tests does not appear to have been carried out. Several investigators have conducted fatigue tests on crankshafts, but these tests have not involved a systematic determination of the effect of crankshaft proportions or material on fatigue strength. Of most importance to the present discussion is that, where details of crankshaft fatigue tests are given, details of the fatigue properties of the crankshaft materials are usually not given. Some interesting observations can, however, be made in respect of the crankshaft fatigue tests already carried out.

Williams and Brown[33] have conducted bending fatigue tests on various forged steel production crankshafts. They found the interesting result that, for the seven types of crankshaft tested, the ratio of the nominal limiting stress in the web to the tensile strength of the crankshaft material covered the range 0·13–0·19. A smaller number of bending fatigue tests referred to by Bandow,[49] carried out on steel crankshafts of size and proportions within the range of those tested by Williams and Brown, gave a range of 0·053–0·124, and some tests carried out by Neugebauer[50] on crankshafts of one particular design gave a ratio of 0·208. For these investigations, therefore, the range becomes 0·053–0·208, and for the total of 12 types of crankshaft tested the average ratio is found to be 0·139.

The results of some bending fatigue tests carried out by Schmidt[51] are not included in these figures, as the dimensions of the crankshafts tested by that investigator are not given. However, the ratio of the web limiting nominal stress to the tensile strength of the crankshaft material in this case was 0·187.

A few bending fatigue tests have also been carried out by Bandow on cast crankshafts of approximately the same size and proportions as the forged crankshafts. For these crankshafts, all of which were of the same cast iron, the ratio of nominal fatigue stress to material tensile strength covers the range 0·133–0·152, with an average of 0·143.

It is seen that the average ratio obtained for cast iron is little different from that obtained for steel, but this would not be the case if the notched bending fatigue properties of the crankshaft material governed the bending fatigue strength of the crankshaft. From these few results it would appear that the unnotched bending fatigue strength of the material has more influence on the crankshaft bending fatigue strength.

In the case of some tests carried out in which forged steel and cast crankshafts were run in test-rigs with bearings misaligned, and which will be discussed more fully later in connection with the elastic modulus of the crankshaft material, the results suggested that notch sensitivity could not be altogether disregarded in estimating crankshaft fatigue strength. In these tests cast crankshafts gave a better fatigue life than steel shafts when motored with the centre bearing misaligned to the same amount, and these results do not appear to depend entirely on the fact that the cast shafts experienced lower bending stresses than the steel shafts owing to the lower elastic modulus of the cast material.

It appears then that, as regards bending, crankshaft materials cannot be rated entirely on the basis of the fatigue strength of specimens with very sharp notches, but notch sensitivity will enter to some extent in a calculation of crankshaft strength, depending on the shape of the crankshaft. This is to be expected, of course, since crankshafts, although irregular in shape, do not usually incorporate the very sharp corners associated with notched fatigue specimens.

If a really sharp notch is present in or near the highly stressed regions of the crankshaft owing to bad design or faulty machining, the notch sensitivity of the material will, however, come more into evidence. Love and Mills[52] have observed the very harmful effect of such notches while conducting bending fatigue tests on forged crankshafts. Some authors point out that the introduction of these very sharp notches will be less harmful in a cast crankshaft than in a forged crankshaft.[53, 54] Moyer[55] gives an example of a cast crankshaft running successfully in spite of the fact that a machinist had left very bad fillets.

With regard to torsional fatigue strength, Bandow has carried out several tests on forged crankshafts giving ratios of nominal journal stress to material tensile strength ranging from 0·056 to 0·121, with an average of 0·095. Tests carried out by Bandow on cast crankshafts give ratios ranging from 0·113 to 0·204, with an average of 0·153, which is considerably better than the value obtained for the steel.

These higher ratios for the cast crankshafts can be explained by referring to the unnotched torsional fatigue properties of the two materials, the unnotched torsional fatigue strength of the cast iron being better in relation to the tensile strength of the material

than is the case for steel. However, the results could also be explained by comparing the notched torsional fatigue strengths of the two materials, and this arises from the fact that the percentage reduction of torsional strength owing to notching for the cast crankshaft materials is only a little less than for steel, as can be seen from Tables II and IV.

Torsional fatigue tests carried out by Lürenbaum[48] revealed that very high ratios of nominal limiting stress to tensile strength could be obtained for steel crankshafts, but these test results could not be compared with those obtained by Bandow, since the proportions of the crankshafts examined in the two cases were not comparable.

The presence of an oil hole in the crankshaft does perhaps constitute a condition similar to that found in the notched torsional fatigue specimen, and this, together with Mickel's demonstration of notch effect in torsion (*see* Fig. 1), suggests that for this type of loading, crankshaft materials should perhaps be rated more on the basis of notched fatigue strength. But, as pointed out already, when comparing cast iron and forged steel it would appear to make little practical difference whether notched or unnotched torsional fatigue strength is used as a basis of comparison.

WEAR PROPERTIES

It is clear that the wear properties of the crankshaft material will find direct expression in the nature of the service life of the crankshaft. The very good wear properties of cast iron are well known, and in connection with cast crankshafts numerous authors point to this favourable quality.[5, 8, 18, 32, 49, 56–61]

The cast shafts may be used very successfully in conjunction with white-metal bearings, and, where high loading exists, copper–lead or lead-bronze bearings may be equally well employed without the necessity for surface hardening the crankshaft as is usual with forged crankshafts.[2, 15, 53, 59, 60, 62] Aluminium-alloy bearings are said to be very suitable for cast iron crankshafts,[30] and Moyer[55] refers to the use of forged aluminium connecting rods running directly in contact with cast crankshafts. West[20] gives an example of very low wear rates being obtained over a period of 2½ years for a cast crankshaft running with R.R. 56 alloy big-end bearings and white-metal main journal bearings. However, in the case of blackheart malleable-iron crankshafts it appears that surface hardening may be necessary in order to obtain the required wear properties.[8, 49]

Users of cast crankshafts verify the superiority of cast crankshafts over steel crankshafts in respect of wear both of journals and mating bearings.[5, 62]

Templeton[5] describes some accelerated bearing-wear tests in which a 5% nickel steel, a mild steel, and a crankshaft cast iron were tested when running in conjunction with bearings containing 89% of tin, 7½% of lead, and 3½% of copper. After 25 hours' running the amounts of the wear on the nickel steel, mild-steel, and cast iron shafts were, respectively, 0·0015, 0·0020, and 0·0007 in., while the corresponding amounts of bearing wear were 0·0020, 0·0010, and 0·0004 in.

Ludicke[63, 64] has carried out accelerated bearing tests, using various forged and cast crankshaft materials running in conjunction with copper–lead bearings. In the testing machine a motor drives a single-throw built-up crankshaft which actuates a connecting rod and piston, the heavy piston employed producing high inertia loading on the big-end test-bearing. The three cast crankshaft materials tested were described as a cast steel, a cast iron, and a cast alloy iron. The cast steel had a carbon content of 0·30% and contained 2·47% of nickel, 0·42% of chromium, and 0·35% of molybdenum ; the cast iron had a carbon content of 2·94% and contained 0·33% of molybdenum and 1·20% of copper ; the cast alloy iron had a carbon content of 1·20% and contained 0·03% of nickel, 0·55% of chromium, and 2·58% of copper.

Very low rates of crankpin wear were obtained with the cast alloy iron, a nickel–chromium–molybdenum steel, a nitrided steel, and a carburized steel. Slightly greater rates of wear were obtained with the cast steel and cast iron, and considerably greater wear rates were obtained with the other steels tested. The minimum bearing wear was obtained with the nitrided steel and the cast alloy iron. Slightly greater rates of wear were obtained with several materials, including the cast steel and cast iron, and the other steels gave considerably greater rates of bearing wear.

Thus, for these tests, the wear with the cast materials was in general much better than with the forged steels, although the nitrided steel and the carburized steel gave results as good as the best obtained for the cast materials, namely, the cast alloy iron.

HARDNESS AND MACHINABILITY

The hardness of the cast materials is probably of interest in connection with machinability as well as with the wear properties.

Although good machinability is invariably claimed for the cast crankshaft materials, it is of interest to note that with one well-known type of crankshaft (Brinell hardness 300) cutting speeds during machining had to be reduced compared with those used during the production of the corresponding steel shaft, and in addition special hammered high-speed tool steels were used.[65, 66]

DAMPING CAPACITY

Damping capacity, or " internal friction," refers to that property of a material whereby imposed energy is absorbed and dissipated as heat.[67] For a member which is set vibrating by cyclic impulses, the magnitude of the vibration will be smaller the greater the damping capacity of the material in the member. Cast iron is known to have a particularly high damping capacity,[67–70] and many authors consider that in this respect it has a big advantage over forged steel for crankshafts.[7, 8, 11, 18, 53, 54, 59, 60, 71, 72]

However, there is some doubt as to how much the damping capacity of a crankshaft material contributes towards reducing crankshaft vibration. The total damping forces acting in the vibrating crankshaft-connecting-rod-piston system arise from several sources,[31, 69] among which are (1) " apparent " damping influences arising from the motion of the reciprocating masses, (2) frictional forces on journals,

gudgeon pins, and cylinder walls, and (3) damping influences caused by impact between mating parts.

Investigations of engine damping suggest that the damping of the material is not a predominant factor,[24, 73] except perhaps in the case of a strong vibration[31, 74]—stronger than should be permitted in a well-designed installation.

Burn[75] states that the proportion of the total damping effect due to the internal damping capacity in the steel parts in an average engine has been estimated at 25–30%, and Lürenbaum[48] states that the material participates in the total damping of the engine to the extent of 30–40%.

The significance of the damping capacity of the cast crankshaft is best observed by reference to crankshaft behaviour in service. Carter[76] gives a diagram in which the variation of the measured torsional vibration amplitude with engine speed for a forged steel crankshaft is compared with that for a cast iron crankshaft when fitted in a five-cylinder engine. He shows that the amplitude of vibration of the cast iron shaft at any particular vibration order is less, but not much less, than the corresponding vibration in the steel shaft.

Peirce[34] has also compared the torsiograph results for a cast iron and a forged steel shaft. He found that at all the vibrational orders investigated the cast iron shaft had considerably greater amplitudes of vibration than the steel shaft. At one order of vibration the cast shaft vibrated with an amplitude almost four times as great as that of the steel shaft.

Lürenbaum[48] found that engine torsiograms taken for forged steel and cast shafts in a particular engine did not show much difference in the peak amplitudes of oscillation at resonance, and Wilson[31] also refers to tests in which results of this kind were obtained.

These various facts indicate that the greater damping capacity of the cast crankshaft material probably has very little favourable effect on crankshaft vibrational behaviour.

MODULUS OF RIGIDITY

The modulus of rigidity of cast iron is somewhat lower than that of steel. Steel has a modulus of rigidity of about 12×10^6 lb./sq. in., while typical values of this property for cast crankshaft materials, as given in Table VI, vary from $7{\cdot}1 \times 10^6$ to $11{\cdot}5 \times 10^6$ lb./sq. in. The lower modulus of the cast iron makes itself felt in the torsional vibration behaviour of the crankshaft, the natural vibration frequency of the crankshaft system being dependent on the modulus of rigidity of the crankshaft material. Several authors point to the possible danger of the reduced vibration frequency in the cast shaft,[29–31, 49, 53, 76, 77] which results in a tendency for the more dangerous critical speeds to be moved into the running range of the engine.

Evidence of the reduced natural vibration frequency is found in the previously mentioned engine tests carried out by Carter,[76] in which the various orders of vibration occurred with the cast shaft at running speeds 28% lower than the corresponding speeds for the forged steel crankshaft.

Another result of the reduced modulus of rigidity is that, for equal amplitudes of torsional vibration, the torsional stresses in a cast shaft will be smaller than in a steel shaft. Although in the foregoing discussion on damping capacity it was shown that vibrational amplitudes in the cast shaft may not be less than for the steel crankshaft, and therefore most of the troubles associated with vibration may still be present with the cast shaft, it is possible that the cast iron crankshaft is preferable to some steel shafts in respect of strength under these conditions. If, for example, one compares the conditions for a 35 tons/sq. in. medium-carbon steel crankshaft and a cast crankshaft made of the inoculated iron described in Table VI, when vibrating with similar amplitudes, it is seen that the stresses in the cast shaft will be about 0·7 of those in the steel shaft. Now the unnotched torsional fatigue strengths of the cast iron and steel are, respectively, $\pm 9{\cdot}7$ tons/sq. in. and about $\pm 10{\cdot}5$ tons/sq. in., and if it can be assumed, as suggested earlier, that crankshaft torsional fatigue strength depends on the unnotched torsional fatigue strength of the crankshaft material, it is clear that under conditions of equal amplitude the cast shaft will be less likely to fail than the steel shaft.

MODULUS OF ELASTICITY

In cast iron crankshafts the lower modulus of elasticity of the material, as compared with that for steel, will presumably result in a tendency for any resonant bending vibrations to occur at lower engine speeds than are found with the corresponding forged steel crankshaft, and, secondly, stresses in the cast shaft will be lower than those in the steel shaft for equal bending deflections.

The bending behaviour of the crankshaft is, however, intimately connected with crankcase rigidity and the nature of the support of the crankshaft in the crankcase. In a well-supported crankshaft, and in the absence of excessive bearing clearance, bending loads will be shared with the crankcase, and it can be seen that the greater proportion of the bending moment will be resisted by the crankcase if the crankshaft is very flexible compared to the crankcase. Carter,[76] for example, considers that while a multi-throw crankshaft should be as stiff as possible torsionally, it should be as flexible as possible in bending. Presumably, adequate crankcase stiffness must accompany these conditions. There is evidence of the effect of crankcase support in the fact that some steel-crankshaft bending failures, occurring when using aluminium alloy crankcases, have been eliminated by adopting the stiffer cast iron crankcases.

Comparing the cast iron and forged steel shafts for equal bending loads, and assuming good crankshaft support, the following conditions appear to apply, firstly, both the crankcase and crankshaft will deflect slightly more in the case of the cast shaft, since for this shaft the crankcase/crankshaft assembly, which resists the bending loads, is more flexible, but, secondly, as already pointed out, the bending moments on the shaft itself will be less in the case of the cast crankshaft. From this it seems that it might be more accurate, where good crankcase support is assumed, to compare the cast iron and steel crankshafts on the basis of equal bending amplitudes rather than on the basis of bending fatigue strength.

Tests in which the cast shaft and the forged steel shaft have been compared in this way are referred to by West[20] and Dwyer.[13] In both cases crankshafts with three main bearings were used and were rotated in a test-rig with the centre bearing purposely out of line with the other bearings. In both series of tests the cast crankshafts gave better results than the steel shafts. This shows the cast crankshaft in a favourable light (*a*) because such tests indicate to some extent the behaviour to be expected from a crankshaft under gaseous and inertia bending loads, and (*b*) because crankshafts are often subjected in service to precisely the type of bending load applied in the tests. The second type of loading would occur as a result of bearing misalignment due to uneven wear[54] (*see also* reference 75, p. 206) or some other such cause.

Various authors refer to the lower stresses and long life found with cast iron crankshafts when running with a misalignment,[2, 8, 20, 76] but Wickenden[72] points out that the lower elastic modulus does not entirely explain the longer life. For the tests referred to by Wickenden, which are presumably the same tests as those described by Dwyer, the stresses induced in the cast crankshaft are considerably lower than those induced in the corresponding forged crankshaft, but if the strengths of the shafts are compared on the basis of unnotched fatigue strength of the crankshaft materials, then the stresses induced in the cast shaft are not sufficiently low to account for its longer life. This applies also to the crankshafts tested by West.

Allowance may also be made for the fact that the stresses in the cast iron shaft will be lower than deduced from the elastic modulus of the iron as usually given. The elastic modulus is determined usually from the very first part of a stress/strain test on the iron, whereas the stress/strain curve of the iron is such that, at a particular stress, the strain is greater than indicated by the elastic modulus determined in this way, and this difference becomes more pronounced with increase of stress. But even if this allowance is made, the test results are still not entirely explained.

Wickenden considers that the additional factor leading to the longer life of the cast shaft is the lower notch sensitivity of the cast material. This would appear to be the case, but it must be borne in mind that earlier in this survey it appeared that crankshaft bending fatigue strength is usually dependent on the unnotched fatigue strength of the material rather than on the notched fatigue strength.

It is evident that the lower modulus of elasticity of the cast iron contributes favourably to the better behaviour of the cast crankshaft in misalignment tests, and would appear also to assist the crankshaft in resisting bending loads arising from normal engine operation. The possible lowering of bending vibration frequencies owing to the lower elastic modulus is probably not a serious matter, since the crankcase—as with gaseous and inertia bending loads—will resist any tendency for the crankshaft deflections to become large.

IMPACT STRENGTH

The impact strength of a material, as normally determined, does not appear to be of any real significance in connection with the selection of materials for crankshafts.[5] Gillett,[78] for example, points out that specimens cut from a well-known type of cast crankshaft give very low Charpy impact values, in spite of the fact that these shafts give very satisfactory service.

Some examples of impact values for cast crankshaft materials are given in Table VI.

Tests carried out under conditions of repeated impact might, however, approach the conditions prevailing in an engine.[5] As a matter of interest, Frémont,[79] considers the crankshaft loading to consist of a series of impacts. Smith[30] refers to some tests in which specimens cut from a cast iron and two forged steel crankshafts were subjected to repeated impact. The cast material compared very favourably with the steel, giving superior life under low-energy impacts and giving comparable results to the steel for impacts involving greater blow energy. Currie and Templeton[54] refer to some favourable results obtained for a complete crankshaft casting which was subjected to repeated blows.

Klingenstein, Kopp, and Mickel[60] consider that the low single-blow impact strength of a cast material may be an advantage in the cast crankshaft. A sudden impact imparted to a steel shaft by a seizure or some other action might cause deformation and result in damage both to the engine bearings and the engine casing, but a similar blow imparted to the cast shaft would, if severe enough, break the cast shaft clean through and at the very worst damage the bearings. These authors add that in some early experiments cast-shaft failures of this kind did occur, but in no case was damage of the remaining parts of the engine observed.

TENSILE STRENGTH

The tensile strength does not appear to be a property directly governing the service behaviour of a crankshaft, but since this property can be determined fairly readily, is commonly made use of, and appears to be related to many of the other mechanical properties of the material, it becomes of great importance when considering materials for crankshafts.

As noted earlier, some very approximate relationships exist between the tensile strength of the cast material and the torsional and bending fatigue strengths and notch sensitivity. However, it is stated that for the higher strength materials there is a tendency for notch sensitivity to be greater,[5, 40, 60] but this does not appear to be true for the cast materials of Tables II and IV. It is said that for an increase of tensile strength, damping capacity is reduced.[5, 60, 80] Also, as can be seen from Table VI, the modulus of elasticity and modulus of rigidity both tend to increase with increase of tensile strength of the cast crankshaft material.

MECHANICAL PROPERTIES : SUMMARY

It will be seen that to ensure best results in service the crankshaft material must show a high torsional fatigue strength and a high modulus of rigidity. To a lesser extent notch sensitivity in torsion is important. The exact significance of bending fatigue strength is not apparent ; this property of the crankshaft depends primarily on the bending fatigue

strength of the material and to a lesser extent on the bending notch sensitivity, but the crankshaft bending behaviour in the engine appears to be partly influenced by the way in which the shaft is supported. Because of this the best results would appear to be dependent on a high bending fatigue strength coupled with a low elastic modulus, which properties, however, are not generally found together. Desirable wear properties appear to exist with practically all of the cast materials. Impact strength and damping capacity are of little importance.

It may be observed that the desirable properties, *viz.*, high torsional fatigue strength, a high modulus of rigidity, and high bending fatigue strength, are in general associated with cast materials of high tensile strength.

ADVANTAGES OF USING CAST CRANKSHAFTS

It appears that of the more important mechanical properties of the material, the fatigue strength, notch sensitivity, and modulus of elasticity together determine whether the cast crankshaft can attain the necessary strength properties to perform its task of transmitting mechanical power; however, having attained the required strength properties in the crankshaft by selecting a particular cast material, one wishes to know how the cast crankshaft will behave in service in comparison with a forged shaft. This service behaviour appears to be governed by the two remaining important properties, namely, wear resistance and modulus of rigidity.

In general, the cast shafts will have superior wear properties to forged shafts which have not been specially treated to give high wear resistance, but the vibration difficulties do not appear to be alleviated with the cast shaft; in fact, the cast shaft appears to intensify the torsional vibration problems, where such exist.

The first advantage of using a cast crankshaft thus lies in its high wear resistance, but since steels can be made to attain this high wear resistance by special treatment, can have better vibrational properties than the cast shafts, and can attain better strengths—as appears to be the case with the higher-strength steels and special processes at least—where lies the reason for using cast crankshafts? The reason is found in the fact that in most cases the cast crankshaft can be produced more cheaply and more quickly than the steel crankshaft.[1, 2, 5, 7, 18, 53, 54, 57, 59, 81]

The cast crankshaft can be cheaper to produce, firstly because the crankshaft casting will usually be cheaper to produce than the corresponding steel forging, owing to the difference in cost of pattern equipment and forging dies, and, secondly, because the crankshaft casting can in general be made closer to the finished crankshaft size than can a forging, less machining being required for the casting. For example, by casting close to size, all machining of crankwebs and counterweights can be eliminated,[2, 5] Similarly, the speed of production may be improved for the casting because of the quicker production of pattern equipment and the shorter machining time required.

An example is available of a crankshaft of 12,000 lb. finished weight being machined from a block forging weighing 36,000 lb.[4, 82] The corresponding rough casting weighed 14,000 lb. In the case of a well-known type of automobile crankshaft the rough casting weighed 65 lb. and the finished shaft weighed 56 lb., whereas the corresponding forging weighed 82 lb. in the unmachined state and 66 lb. when machined.[13] The number of production operations was reduced from 62 to 54 when the change was made to the cast shaft.[65]

Table VII, which is taken from a paper by Templeton,[5] shows some important savings in material and machining time achieved by using cast crankshafts instead of forgings in a number of engines during the recent war. At that time not only was the saving of material of great importance, but in addition a serious handicap to crankshaft production existed in the form of a " bottleneck " in forging and machining capacity.[5, 54, 82]

The economies gained with cast crankshafts become greater as the crankshafts become larger, the cost of pattern equipment becoming very small in relation

Table VII

COMPARATIVE FIGURES OF MACHINING HOURS AND MATERIAL REMOVED IN THE PRODUCTION OF FORGED AND CAST CRANKSHAFTS (REFERENCE 5)

Type of Engine	Forgings			Castings			Savings with Cast Crankshafts	
	Rough Weight, lb.	Finished Weight, lb.	Machining Time, hr.	Rough Weight, lb.	Finished Weight, lb.	Machining Time, hr.	Material, lb.	Machining Time, hr.
Diesel								
6-cylinder	2520	657	160	700	637	80	1800	80
6-cylinder	1344	287	100	256	216	30	1017	70
6-cylinder	1316	330	75	364	354	34	976	41
4-cylinder	924	279	73	300	278	55	623	18
4-cylinder	672	140	60	177	141	34	496	26
4-cylinder	630	168	84	159	126	51	429	33
Compressor								
4-cylinder	616	93	55	114	87	24	496	31
2-cylinder	364	72	65	101	74	35	265	30

to the cost of the larger cast crankshaft ;[60] the economies also become greater as the crankshafts become more complicated in shape,[54] and even further relative gains are obtainable when the crankshafts are made in small numbers.[2, 5, 30, 49] Where small numbers of steel shafts are required the high cost of the forging equipment will probably be avoided by cutting each crankshaft from a solid piece of steel, but in such a case the cost of the machining becomes excessive. The cast crankshaft will probably not be able to compete with the small crankshaft of comparatively simple shape forged in large quantities and which can be made with a fairly small machining allowance.[30] Jungbluth[56] points out that drop forgings of simple shape may be cheaper than castings, and cites a case in which the use of some cast steel crankshafts for locomotives was discontinued because the comparatively simple shaped crankshafts could be made more cheaply by forging.

As pattern equipment can be made cheaply and quickly, considerable alteration in the design of the cast crankshaft can be made during the experimental stages of production.[2, 18, 53]

The incorporation of balance weights in the casting presents little difficulty.[30, 53, 83] Bergdoll[19] points out that this was a major factor in the decision of an American firm to change over to cast crankshafts for compressors. Similarly, the coring of bearings can be introduced, making a lighter shaft.[2, 7, 53, 54, 59] and reducing bearing inertia loads.[53]

It is pointed out that full use should be made of the shaping properties of the cast material in order that the crankshaft should attain a maximum of "structural durability" or "form strength," and for this purpose use may be made of special design features which would be very difficult or impossible to use in the forging.[49, 53, 59]

Further differences between the forged and the cast crankshaft may appear in respect of heat-treatment. The forged crankshaft usually requires various stages of heat-treatment during the course of its manufacture,[5, 7] whereas most of the cast crankshaft materials do not require any heat-treatment subsequent to casting, apart perhaps from a stress-relief treatment.[2, 5, 53, 59]

In one case[65] it is suggested that the absence of need for cold-straightening a cast crankshaft is of major importance in reducing production costs.

It will be seen that, apart from the high wear resistance, all of the foregoing points raised in favour of the cast crankshaft are matters of production costs and speed of production. The forged crankshaft can have the advantages of balance weights and cored holes, but at extra cost. The special stress-relieving features that may be introduced into the cast shaft are perhaps not obtainable with the forged shaft, but in any case the value of using these special designs is in question, as will be seen later.

The various points can be summarized in the statement that the casting process provides a means of quickly and cheaply supplying a crankshaft of very high wear resistance and of the most desirable shape, this shape being such as to impart to the engine certain favourable characteristics which could not be obtainable with the forged shaft except at a high cost.

The disadvantage of possible vibrational trouble must not be forgotten, but for the many engines which already incorporate vibration dampers the lower vibration frequency of the cast crankshaft would not appear to be a handicap. In other engines, and especially large ones, perhaps the fitting of a cast crankshaft with the addition of a damper will improve the engine and still give a saving of cost. If there is no saving of cost there is still the advantage of good wear resistance. Smith[30] remarks that the lower cost of the cast crankshaft may not be the determining feature in the future, and that the advantages in bearing conditions may be most important. In many engines the problem of torsional vibration trouble will not, of course, arise.

CAST CRANKSHAFT MATERIALS

In order that the cast crankshaft should retain its basic advantage, that of economy of production, the crankshaft material, apart from having the required strength and wear properties, must be cheap to produce, readily machinable, and easy to cast. It is clear that where a small number of shafts are being made the time and trouble involved in determining a satisfactory casting technique must be kept low, but where a large number of shafts of a particular design are being made this factor may not be so important in relation to total cost. It is in this latter type of production then that the higher-strength materials, which are usually more difficult to cast satisfactorily,[20] can probably be used most economically. It is of interest to note that one automobile firm, for its large-scale cast-crankshaft production, has adopted a low-carbon high-strength material.

CAST STEEL

Cast steel was used for some railway-engine crankshafts early in this century and before.[9, 10] More recently, in 1932,[16] one foundry began the development of cast steel crankshafts and by 1934 had supplied a large number of motor-car and other crankshafts which proved very successful. The material had a tensile strength of 46 tons/sq. in. and an izod impact strength of 46 ft.lb. Vennerholm[84] refers to the use of a nitrided cast steel crankshaft in a 600-h.p. tank engine during the recent war.

Reference is made to tests carried out by the Japanese on a cast steel crankshaft.[85] These tests are said to have met with fair success. The composition of the steel used was: Carbon 0·35–0·43%, silicon 0·50–0·80%, manganese 0·90–1·20%, phosphorus 0·04% (maximum), and sulphur 0·04% (maximum).

Reference is made also to the use of some 26–32 tons/sq. in. cast steel webs for a built-up crankshaft,[75] and in another case complete single crankthrows of cast steel were made for a large built-up crankshaft.[86] In the latter case the material had the following composition: Carbon 0·22%, silicon 0·44%, manganese 0·45%, phosphorus 0·028%, and sulphur 0·024%. The tensile strength of the material was 32 tons/sq. in. and the bending endurance ratio was 0·33.

Details of tests carried out by Gough and Pollard on an alloy cast steel for crankshafts are given in

Tables V and VI. The tensile strength of this material was 52·3 tons/sq. in., the bending endurance ratio was 0·43, and the ratio of torsional fatigue strength to bending fatigue strength was 0·55–0·63. A sharp circumferential notch reduced the bending fatigue strength by 35% and the torsional strength by 26%.

For some tests carried out by Mailänder[43] on a 28 tons/sq. in. cast steel, a bending endurance ratio of 0·52 was obtained, with a 32% decrease of strength owing to a notch. Ratios of torsional fatigue strength to bending fatigue strength for four steels with tensile strengths ranging from 24 to 39 tons/sq. in. varied from 0·61 to 0·74, increasing with increase of tensile strength. The average figure for bending endurance ratio for these steels was 0·37.

Bending endurance ratios for several cast steels tested by Sims and Dahle[87] gave an average value of 0·46, and the average reduction of bending strength owing to a notch was 33%. A 39 tons/sq. in. copper cast steel tested by Russell and Welcker[88] gave an endurance ratio of 0·56 and a reduction of bending strength owing to a notch of 43%.

Wear tests carried out by Ludicke[63, 64] and referred to earlier showed good results for a nickel–chromium–molybdenum cast steel.

HIGH-CARBON CAST STEEL

A material which has been used for certain automobile crankshafts on a large scale and which has been referred to by a variety of names,[1, 7, 8, 13] is perhaps most frequently called a cast alloy steel.[18, 62] Its composition, as given in 1940,[89] is as follows: Carbon 1·35–1·60%, manganese 0·70–0·90%, silicon 0·85–1·10%, phosphorus 0·10% (maximum), sulphur 0·08% (maximum), copper 1·50–2·00%, and chromium 0·40–0·50%. The cupola charge consists of 40% of return scrap (gates and risers), 20% of basic pig, and 40% of steel scrap. The crankshafts are given the following heat-treatment:[18] Held for 20 min. at 1650° F.; air quenched to a minimum of 1200° F.; reheated to 1480° F. and held for 1 hr.; and, finally, cooled in the furnace to 1000° F. in 1 hr. This process produces a fine-grained structure containing cementite and a small amount of temper carbon.[49]

Some physical properties from test-bars of high-carbon cast steel, outlined in 1935[1]—for material which had a very slightly different composition than that just quoted—are: Tensile strength, 48 tons/sq. in.; elongation 3·0%; reduction in area, 2·50%; Brinell number, 269.

A very similar material was tested by Cornelius[37] and is referred to as high-carbon cast steel (*a*) in Tables I and II. It will be seen that a very low endurance ratio was obtained, but Cornelius considers that the results cannot be truly representative of the material. He points out that the test-bars were possibly not completely sound, as very great difficulty had been experienced in attempting to produce test-bars free from obvious defect. Gough and Pollard[12] also carried out tests on an apparently similar material. This material is referred to as a copper–chromium iron in Tables V and VI. A tensile strength appreciably lower than that usually attributed to the high-carbon cast steels was obtained, but fairly high values are obtained for the bending and torsional endurance ratios. Russell and Welcker[88] conducted tests on specimens cut from a high-carbon cast steel crankshaft and obtained a tensile strength of 35 tons/sq. in., a bending endurance ratio of 0·56, and a reduction of strength of 30% owing to a square notch.

MALLEABLE IRON

Reference is made to the use of malleable iron for crankshafts in Germany,[8, 49] and fatigue tests on malleable iron for crankshafts have been carried out by Bandow,[49] Cornelius,[37] and Geiger.[70] The results of Bandow's crankshaft tests on a blackheart malleable iron are included in the following data from his torsional tests on model crankthrows (journal diameter (d) = 14 mm., fillet radius (r) = 2 mm., $r/d = 0·143$):

	Particulars of Journal	Torsional Fatigue Strength, tons/sq. in.
Pearlitic iron ...	Solid	6·4–7·0
Blackheart malleable iron	Solid	7·3–7·6
	Solid with transverse bore ...	5·1–5·7
	Solid, flame hardened	8·6–8·8
	Solid with transverse bore, flame hardened ...	8·6–8·9
Steel St.50.11 (torsional fatigue strength of plain bar 12·7 tons/sq. in.)	Solid	8·9
	Solid with transverse bore ...	6·4

The results of Bandow's fatigue tests on crankshafts are given in Table VIII. The compositions and tensile strengths of the irons used for these fatigue tests were as follows:

	Blackheart Malleable Iron	Pearlitic Iron
Carbon, %	2·26	3·38
Silicon, %	0·93	1·17
Manganese, % ...	0·65	1·18
Sulphur, %	0·052	0·103
Phosphorus, % ...	0·17	0·05
Tensile strength, tons/sq. in.	22	17

It will be seen that some of the malleable-iron crankshafts tested were flame hardened. It is necessary to do this in the case of blackheart malleable iron in order to give the iron sufficient wear resistance for use in crankshafts.[32, 49, 70]

The compositions of the three malleable irons tested by Cornelius are included in Table I and the test results are included in Table II. It will be seen that the tensile strengths of these irons were about 20 tons/sq. in., bending endurance ratios for two of the irons were 0·5 and 0·45, respectively, corresponding reductions owing to notches were 38% and 30%, and the ratio of torsional fatigue strength to bending fatigue strength for one of the irons was 0·84. The Brinell hardness values of two of the irons were low, being 128 and 108, respectively. For two malleable irons tested by Geiger, the tensile strengths of which were 34 tons/sq. in. and 37 tons/sq. in., respectively, corresponding values of 9·2 tons/sq. in. and 9·3 tons/sq. in. were obtained for torsional fatigue

strength. Both irons gave a value of 10% for the reduction of torsional strength owing to notching. Cornelius and Geiger consider their results in relation to those obtained by several other investigators.

The work of Russell and Welcker[88] also includes some fatigue tests on malleable irons. An unalloyed malleable iron and a 1·12% copper malleable iron gave the following respective mechanical properties: Tensile strengths, 24 tons/sq. in. and 26 tons/sq. in.; bending fatigue ratios, 0·54 and 0·56; bending-fatigue-strength reductions owing to a notch, 35% and 34%; Charpy **V**-notched impact strengths, 5·5 and 7·0 ft.lb. A handbook describing American malleable iron[90] gives, for standard malleable iron, a tensile strength of 24 tons/sq. in., a bending endurance ratio of 0·575, and a bending-fatigue-strength reduction owing to a notch of 33%.

The use of pearlitic malleable iron for crankshafts has been referred to,[90, 91] and Sheehan[3] mentions that one possible development in respect of cast crankshafts is the use of heat-treated pearlitic malleable iron which could be produced to give a tensile strength of 40 tons/sq. in. Peace[91] refers to a 1·84% nickel pearlitic malleable iron which, hardened and tempered, gave a tensile strength of 60 tons/sq. in. and a Brinell hardness of 343.

The pearlitic malleable irons are developed from blackheart malleable iron, which has a total carbon content of about 2·4% and a completely ferritic matrix.[91] In the pearlitic malleable iron the ferrite matrix of normal blackheart malleable is replaced by pearlite or some other transition structure of the austenite, this condition being brought about by heat-treatment or the use of alloys. The pearlitic malleable iron has good machining properties and very good wear properties,[90] and presumably these wear properties are attained without the necessity for flame hardening as is the case with ordinary malleable iron.

Sheehan describes a typical pearlitic malleable iron for use in crankshafts. This material[92] has the following average composition: Carbon 2·65%, silicon 1·35%, manganese 0·40%, sulphur 0·13%, and phosphorus 0·05%. Peace[91] gives a list of different pearlitic malleable irons. These vary in tensile strength from 30 to 54 tons/sq. in., the Brinell hardnesses varying from 150 to 350. Some fatigue properties for a 35 tons/sq. in. pearlitic malleable iron are given as: Bending endurance ratio, 0·39; bending-fatigue-strength reduction owing to a notch, 17·5%. The modulus of elasticity for pearlitic malleable irons varies from 26×10^6 to 28×10^6 lb./sq. in.

Table VIII

FATIGUE TESTS ON CRANKSHAFTS (BANDOW) (REFERENCE 49)

Journal diameter (d) = 48 mm.; fillet radius (r) = 2 mm.; r/d = 0·042

Material	Remarks	Bending Fatigue Strength,* tons/sq. in.	Torsional Fatigue Strength,† tons/sq. in.
Pearlitic iron‡	...	3·2	3·5
Pearlitic iron‡	Flame hardened	...	2·9
Blackheart malleable iron‡	Flame hardened	4·1	3·8
53-ton steel	...	5·7	6·2–6·4
83-ton steel	...	...	6·4–6·7

* Fatigue strength based on section of web
† Fatigue strength based on journal section
‡ For composition, see page 260

INOCULATED IRON

A type of material which has been used to a considerable extent for making crankshafts both in this country[81] and in America[4, 19] is made by a process which involves the inoculation of the material with calcium silicide added at the cupola spout.[93, 94] The raw materials are selected carefully, and sometimes such alloys as copper, chromium, molybdenum, and nickel are used.[54] The iron has a pearlitic structure and the graphite occurs as curved flakes.[96]

One grade of this material which has been used for crankshafts has a tensile strength of 22·5 tons/sq. in., a modulus of elasticity of 21×10^6 lb./sq. in., a fatigue strength of 10 tons/sq. in., and a Brinell hardness of more than 220.[95] The reduction of bending fatigue strength owing to notching is given as 13%.[96] In another case,[54] the fatigue strength is given as 11·8 tons/sq. in., with a fatigue-strength reduction owing to notching of 13·5%. Another grade of the material which has been used for crankshafts has a tensile strength of 24·5 tons/sq. in., a modulus of elasticity of 23×10^6 lb./sq. in., a fatigue strength of 12 tons/sq. in., and a Brinell hardness of more than 230.[95]

Some mechanical properties given by Templeton[5] for a material of this class are as follows: Tensile strength, 26 tons/sq. in.; bending fatigue strength, 14·3 tons/sq. in.; loss of fatigue strength owing to a notch, 12%; modulus of elasticity, 22×10^6 lb./sq. in.; modulus of rigidity, $8·7 \times 10^6$ lb./sq. in.; torsional fatigue strength, 11·5 tons/sq. in.; Brinell hardness, 240. A reference by Templeton to the work of Gough and Pollard suggests that the inoculated iron examined by the latter investigators and referred to in Tables V and VI is a material of the class at present under discussion.

A crankshaft iron of this type, tested by Eagan,[97] had the following chemical composition: Carbon 2·84%, silicon 1·40%, manganese 0·67%, phosphorus 0·11%, sulphur 0·059%, nickel 1·69%, chromium 0·16%, molybdenum 0·46%, and copper 0·15%; specimens cut from a crankshaft in the as-cast state gave the following mechanical properties: Tensile strength, 22·5 tons/sq. in.; fatigue strength, 7·8 tons/sq. in.; Brinell hardness, 217; izod strength, using unnotched 0·798-in. dia. specimens, 18 ft.lb.

CHROMIUM–MOLYBDENUM IRONS

One foundry has developed and used a chromium–molybdenum iron for the production of a large number of crankshafts.[59, 83] The iron is prepared from specially refined pig irons in which the molybdenum and chromium are already present, but the final composition and structural adjustments are made at the ladle to suit particular types of castings.

The composition[53] is: Carbon 3·15–3·35%, silicon

1·70–1·95%, sulphur 0·10% (maximum), phosphorus 0·10% (maximum), manganese 0·60–0·85%, chromium 0·30–0·50%, and molybdenum 1·00–1·35%. No heat-treatment is required.[59] The structure is described as having a sorbitic pearlite matrix with well-dispersed graphite flakes.[53] Some mechanical properties of this material[53] are : Tensile strength, 20–22 tons/sq. in. ; modulus of elasticity, 18×10^6 lb./sq. in. ; modulus of rigidity, $8{\cdot}0 \times 10^6$ lb./sq. in. ; Brinell hardness, 241–280.

West[20] carried out tests on various alloy cast irons in order to develop a material for cast crankshafts. These alloys involved the use of nickel, molybdenum, chromium, and copper. From preliminary experiments he decided that chromium and molybdenum would be likely to assist in securing high strength characteristics combined with ease of casting, and he finally chose an iron of the following composition : Carbon 3·0%, silicon 1·8%, manganese 1·00%, sulphur 0·05%, phosphorus 0·20%, chromium 0·21%, molybdenum 0·78%. This material had a tensile strength of about 23 tons/sq. in., a bending fatigue strength of about 7·5 tons/sq. in., and an elastic modulus of about $17{\cdot}7 \times 10^6$ lb./sq. in. A crankshaft of this material, as mentioned earlier, behaved very well in comparison with two steel shafts, when motored with the centre bearing misaligned. Later, a 74-h.p. four-cylinder petrol engine using a crankshaft of this type was put into service and gave very satisfactory results, but crankshafts of this material fitted to two compression-ignition engines failed very quickly.

NICKEL–MOLYBDENUM IRONS

A type of iron which has been used in one foundry in America for the production of a large number of crankshafts over a wide range of sizes[2] has a composition[18] as follows : Carbon 2·40–2·80%, silicon 2·25–2·75%, sulphur 0·10% (maximum), phosphorus 0·15% (maximum), manganese 0·80–1·20%, nickel 1·00–1·20%, and molybdenum 1·00–1·20%. The composition is in practice varied in accordance with the size of crankshaft being cast. No heat-treatment is required.[2, 18] In another case[82] the composition given for an iron produced at this foundry is similar to the composition just given but with the addition of 0·17% of chromium. Some mechanical properties are : Tensile strength, 35 tons/sq. in. ; modulus of elasticity, 19×10^6 lb./sq. in. ; modulus of rigidity, $7{\cdot}0 \times 10^6$ lb./sq. in. ; Brinell hardness, 292. It would appear that this material is the one that has been used in America for submarine-engine crankshafts.[3]

Walls[18] gives the compositions and mechanical properties of two nickel–molybdenum crankshaft irons. The first iron had a composition of : Carbon 3·04%, silicon 2·07%, manganese 0·45%, nickel 2·03%, and molybdenum 0·34% ; the mechanical properties were as follows : Tensile strength, 23 tons/sq. in. ; elastic modulus, $18{\cdot}4 \times 10^6$ lb./sq. in. ; bending fatigue limit, 12 tons/sq. in. ; reduction of bending strength owing to a notch, 13% ; Brinell hardness, 277. The second iron had the following composition : Carbon 3·06%, silicon 2·17%, manganese 0·62%, nickel 1·70%, and molybdenum 0·62%. The mechanical properties were : Tensile strength, 24 tons/sq. in. ; elastic modulus, $18{\cdot}5 \times 10^6$ lb./sq. in. ; bending fatigue limit, 12 tons/sq. in. (approximately) ; reduction of bending strength owing to a notch, 7% (approximately) ; Brinell hardness, 241.

A typical specification given by Smith[30] for a nickel–molybdenum crankshaft iron is : Carbon 3·0%, silicon 2·0%, manganese 0·5%, nickel 2·0%, and molybdenum 0·5%. Mechanical properties are : Tensile strength, 23 tons/sq. in. ; bending fatigue strength 12 tons/sq. in. ; modulus of rigidity, $7{\cdot}5 \times 10^6$ lb./sq. in. ; Brinell hardness, 250. References are also made to other nickel–molybdenum crankshaft irons.[18, 98]

The chemical compositions and mechanical properties of nickel–molybdenum crankshaft irons tested by Cornelius[37] have been referred to earlier in the present paper (*see* Tables I and II).

ACICULAR IRON

A type of iron which has been used to some extent for cast crankshafts and the use of which is increasing, is acicular cast iron.[3, 93, 94, 99] In this material the acicular, or needle-like, structure (or acicular ferrite) is produced by using alloy additions smaller than those normally required to produce a martensitic structure, but greater than those producing a pearlitic structure.[100] The tensile strength is usually in the range 27–35 tons/sq. in., although greater values may be obtained.[99] Other properties are : Brinell hardness, 260–340 ; izod strength on a 0·798-in. dia. plain bar, 25–40 ft.lb. A simple thermal treatment, which also serves as a stress-relief treatment, may markedly increase the tensile strength, and, while not reducing

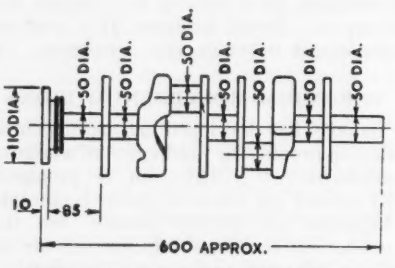


Fig. 3—Design of automobile crankshaft tested by Bandow. Dimensions in millimetres

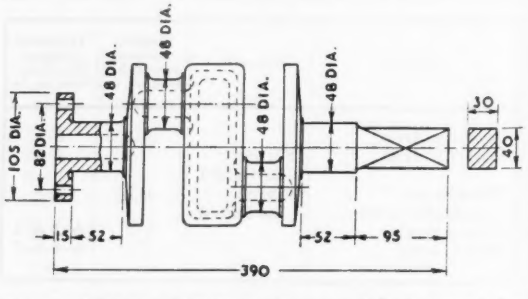


Fig. 4—Design of Volkswagen crankshaft tested by Bandow. Dimensions in millimetres

Table IX

FATIGUE TESTS ON CRANKSHAFTS ILLUSTRATED IN FIGS. 3 AND 4 (BANDOW REFERENCE 49)

Crankshaft Design	Material	Journal Diameter (d), mm.	Fillet Radius (r), mm.	r/d	Bending Fatigue Strength,* tons/sq. in.	Torsional Fatigue Strength,† tons/sq. in.
Volkswagen shaft, Fig. 4	Pearlitic iron	48	2	0·0416	...	3·8–4·1
Automobile shaft, Fig. 3	High-carbon cast steel	50^{+}_{+}	1·5	0·0288	6·7	5·4
Automobile shaft, Fig. 3	Pearlitic iron	50^{+}_{+}	1·5	0·0288	...	3·5–3·8

* Fatigue strength based on section of web
† Fatigue strength based on journal section
‡ Approximate value

the Brinell hardness, gives a pronounced improvement in machinability.[100]

The composition of acicular iron[99] is as follows: Carbon 2·9–3·1%, silicon 1·6–2·6%, manganese 0·8–1·2% sulphur 0·15% (maximum), phosphorus 0·15% (maximum), chromium 0·25–0·6%, and moybdenum 0·7–1·2%. Nickel is added in amounts depending on the casting sectional thickness, varying from 1·0 to 1·4% for a thickness of ½–1½ in. to 3·6–4·5%, for section thicknesses of from 7 to 10 in. For all castings up to 2½ in. sectional thickness the silicon constituent should be in the range 2·2–2·6%, and in all cases 0·5–0·7% of the silicon should be added as a ladle addition, or inoculant, in the form of crushed ferrosilicon. Chromium additions are used for only comparatively heavy sections.

A crankshaft iron developed by one firm and which has a tensile strength of 34·5 tons/sq. in., a modulus of elasticity of 21×10^6 lb./sq. in., a modulus of rigidity of $8{\cdot}6 \times 10^6$ lb./sq. in., a bending fatigue

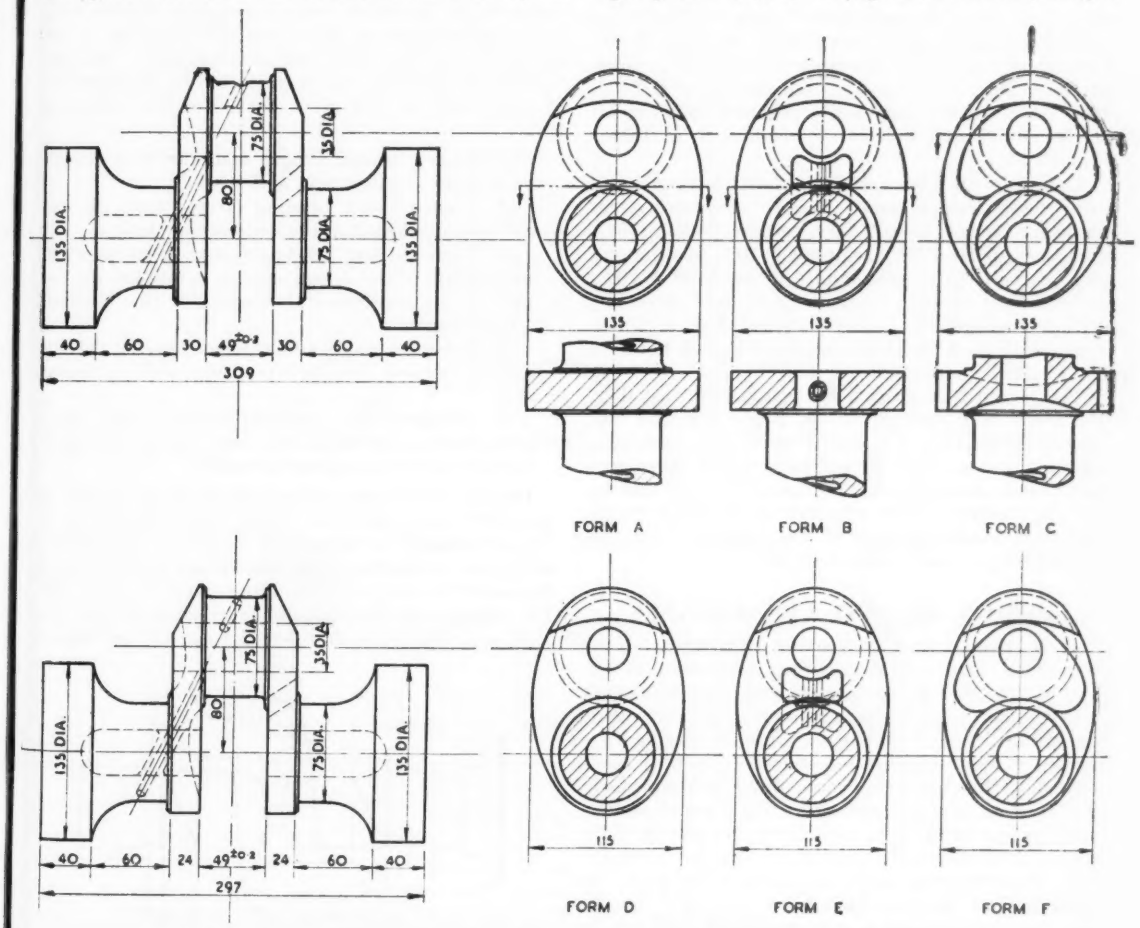


Fig. 5—Cast-crankshaft designs investigated by Bandow. Dimensions in millimetres

Table X

FATIGUE TESTS ON CAST CRANKSHAFTS ILLUSTRATED IN FIG. 5

Journal diameter (d) = 75 mm.; fillet radius (r) = 5 mm.; r/d = 0·066

Web Form	Bending Fatigue Strength,* tons/sq. in.	Torsional Fatigue Strength,† tons/sq. in.
A	3·3	3·2–3·4
B	3·3	2·5–2·7
C	3·5	3·5–3·6
D	3·0	3·1–3·2
E	...	2·5–2·7
F	...	3·2–3·3

* Fatigue strength based on full rectangular section of web
† Fatigue strength based on journal section

limit of 15·5 tons/sq. in., a torsional fatigue limit of 12·8 tons/sq. in., and a Brinell hardness of 270 appears to be an acicular iron.[30]

OTHER MATERIALS

Reference is made to a nickel–chromium iron crankshaft for a single-cylinder engine.[55] The composition of this iron was as follows: Carbon 3·30–3·40%, silicon 1·70%, manganese 0·6–0·8%, phosphorus 0·20%, nickel 2·0%, and chromium 0·75%. Tests on a nickel–chromium crankshaft iron carried out by Gough and Pollard are referred to in Tables V and VI.

A material used for cast crankshafts in single- and two-cylinder compressors[101] has the following composition: Carbon 2·40–2·80%, silicon 2·25–2·75%, manganese 0·80–1·20%, sulphur 0·10% (maximum), phosphorus 0·15% (maximum), nickel 1·00–1·20%, molybdenum 0·40% (minimum), and chromium 0·25% (maximum). The material has a tensile strength of 25–31 tons/sq. in. and a Brinell hardness of 255–321.

The pearlitic irons used for crankshafts tested by Bandow[49] and referred to on pages 260 and 265, and in Tables VIII, IX, and X were irons containing very little or no alloy. It will be seen that these irons had tensile strengths varying from 17 to 23 tons/sq. in. In another case[60] reference is also made to the use of a crankshaft iron of the pearlitic type containing only a small amount of alloy.

DESIGN OF CAST CRANKSHAFTS

It is stressed that in the cast crankshaft full use should be made of the shaping properties of the material so that in each application the crankshaft takes a form giving a maximum of "structural durability."[54, 57, 60] Changing from a forging to a casting without modification of design is not favoured, although this has been successfully accomplished.[4] The fundamental principle of getting a sound casting, and thereby utilizing to the full the properties of the material, should be foremost in the designer's mind,[54] and understanding and co-operation between the designer and the foundryman are essential.[2, 102] In one foundry at least a cast crankshaft will not be produced unless the management are first allowed to act as design consultants in respect of that crankshaft.[53, 83]

In order to get a homogeneous sound casting it is desirable to use cores,[5] and it will be seen that this practice has other advantages also. Johnstone[102] observes that the operating stresses which will later be imposed on the finished structure follow some of the same laws which govern the behaviour of fluid metal in the mould, and that to a "fascinating" degree the design which is best from a foundry standpoint is also best for the distribution of operating stresses in the finished crankshaft. In this connection Klingenstein, Kopp, and Mickel[60] point out that tubular bodies are more efficient than solid ones in transmitting stress.

With the cast crankshafts the span between bearings should be as short as possible, and it is good practice to use bearings on both sides of each crankthrow.[53, 83] Templeton[5] states that it is possible to reduce the length of the bearings because of the greater loading which cast iron will stand.

Although it is pointed out that in the cast shaft full advantage should be taken of the possibilities of design, thus obtaining a maximum of crankshaft strength, so far there does not appear to be very much information to show just what are the most favourable designs for cast crankshafts. In this connection, however, a report written by Bandow[49] is of great interest and gives details of the following tests:

(1) Some torsional fatigue tests on small model crankthrows of cast iron and steel.

(2) Torsional and bending fatigue tests on cast and forged crankshafts of automobile design.

(3) Torsional and bending fatigue tests on some crankshafts of the design used in a well-known car and on an experimental design for the German "Volkswagen."

(4) Torsional and bending fatigue tests on various designs of cast crankshafts using one particular iron.

(5) Torsional and bending fatigue tests on a crankshaft of special design and cast in the high-carbon cast steel referred to earlier.

Details of the tests referred to in (1) are given on page 260. Data from the fatigue tests referred to in (2) are outlined in Table VIII, and the compositions and tensile strengths of the blackheart malleable and the pearlitic irons concerned are given on page 260. The designs of the automobile crankshaft and the Volkswagen crankshaft referred to in (3) are shown

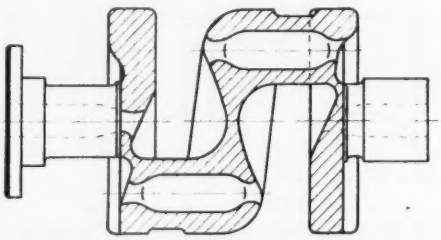


Fig. 6—Special crankshaft design (Bandow)

in Figs. 3 and 4, respectively, and details of the fatigue tests mentioned are given in Table IX ; the compositions and tensile strengths of the high-carbon cast steel and the pearlitic iron mentioned in Table IX were as follows :

	High-Carbon Steel	Pearlitic Iron
Carbon, %:	1·40–1·60	2·79–3·30
Silicon, %	0·90–1·10	1·58–2·00
Manganese, % ...	0·40–0·60	0·70–0·88
Phosphorus, % ...	0·05	0·14–0·15
Sulphur, %	0·04	0·092–0·100
Copper, %	1·50–2·00	0·30
Molybdenum, % ...	...	0·70
Chromium, % ...	0·40–0·50	...
Tensile strength, tons/sq. in.	44–48	18–20

The crankshaft designs referred to in (4) are illustrated in Fig. 5, and details of the fatigue tests mentioned are given in Table X ; the composition and tensile strength of the particular iron concerned were as follows :

Carbon, %	3·27
Manganese, %	1·04
Silicon, %	1·14
Phosphorus, %	0·159
Sulphur, %	0·089
Nickel, %	0·08
Tensile strength, tons/sq. in. ...	23

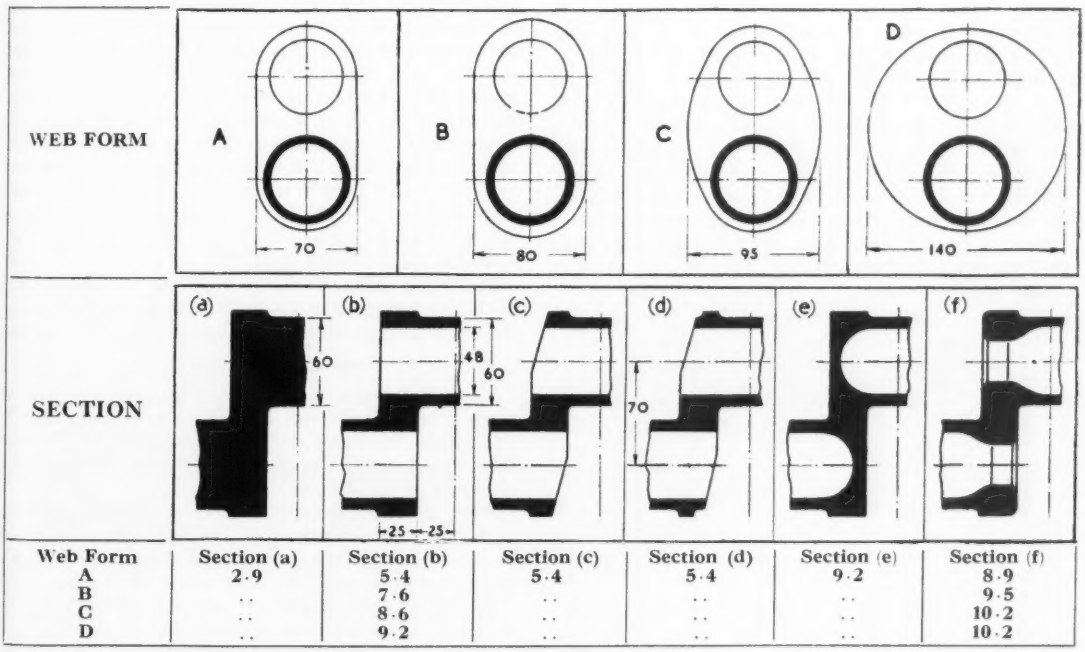
The special crankshaft design referred to in (5) is illustrated in Fig. 6, and fatigue tests on the high-carbon cast steel (journal diameter, 48 mm.) in this case gave bending fatigue strengths, based on the area of the fracture, of from 6·0 to 6·4 tons/sq. in., and torsional fatigue strengths, based on the journal section, of from 7·6 to 7·9 tons/sq. in.

Lürenbaum[48] has carried out some very interesting tests in which the torsional fatigue strength of various designs of forged crankshaft were investigated. The test results are given in Fig. 7. He also conducted tests in which the torsional fatigue strengths of crankshafts of steels and cast materials of one particular design were compared. These tests are outlined in Table XI.

Most of the interesting features of Bandow's and Lürenbaum's reports are discussed separately in different sections of the present survey.

It will be noted that Lürenbaum's work in respect of design was carried out on forged crankshafts, and in the following discussion of the various details of cast-crankshaft design various references to the experience gained with forged crankshafts will be made. In spite of the fact that Mickel[47] considers (in contradiction to the work of Lürenbaum) that forged steel crankshafts will not react very strongly to changes of shape, and cast iron crankshafts will, it is the present author's view that the results of tests involving the investigation of design in relation to forged crankshafts will to a great extent be applicable to the design of cast crankshafts.

The difference between two materials in reaction to design changes may become large where very sudden changes of section exist, in which case the strength of the part is determined by two factors,



Web Form	Section (a)	Section (b)	Section (c)	Section (d)	Section (e)	Section (f)
A	2·9	5·4	5·4	5·4	9·2	8·9
B	..	7·6	..	..	..	9·5
C	..	8·6	..	..	..	10·2
D	..	9·2	..	..	..	10·2

Fig. 7—Torsional fatigue strength of forged steel crankshafts. The figures set out in tabular form underneath the web-form and section designs represent the torsional fatigue strengths for the different combinations of web outline and section, in tons per square inch. The dimensions indicated on the designs are in millimetres. The crankshaft material is 35–45 tons/sq. in. carbon steel (Lürenbaum)

Table XI

CRANKSHAFT TORSIONAL FATIGUE TESTS USING DIFFERENT MATERIALS BUT THE SAME CRANKSHAFT DESIGN (LÜRENBAUM (REFERENCE 48))

The design used was that of section *d* and web-form *A* in Fig. 7

	Low-Alloy Cast Iron	High-Alloy Cast Iron	High-Carbon Cast Steel	40–45-Ton Forged Steel	60–65-Ton Forged Steel	80-Ton Forged Steel
Composition:						
Carbon, %	3·25	2·80	1·43	...	...	...
Silicon, %	1·92	1·60	0·93	...	...	...
Manganese, %	0·64	0·50	0·69	...	...	...
Phosphorus, %	0·24	0·06	0·07	...	...	...
Sulphur, %	0·02	0·02	0·04	...	...	...
Copper, %	...	1·50	1·64	...	...	...
Nickel, %	0·48	0·80	...	...	...	...
Chromium, %	0·75	0·20	0·55	...	...	...
Molybdenum, %	0·50	0·70	...	...	...	...
Torsional fatigue strength of crankshaft, tons/sq. in.	2·9	3·3	3·7	4·4	5·7	8·4

namely, (1) the local stress state set up by the general shape of the part, and (2) the additional weakening effect of the "notch." In crankshafts the notch effect, or a measure of the notch effect, may come into force where, for example, there are sharp fillets or oil holes.

In the absence of sharp notches some small difference of reaction to design changes may of course exist with two materials owing to a difference of "stress/strain" properties.

FILLETS

The bending and torsional fatigue strengths of forged steel crankshafts have been shown to be greatly influenced by the size of the fillet radius.[103] The measurement of stresses in the fillets of forged crankshafts also suggests that a considerable change of crankshaft strength will accompany a change of fillet radius.[28, 104] Mickel's tests, illustrated in Fig. 1, show the very different reactions of a steel and a very low-strength cast iron model crank to changes of fillet radius. Presumably an average crankshaft iron, which would have a tensile strength greater than that of the iron tested by Mickel and would show a greater measure of notch sensitivity, would react more than the low-strength cast iron but less than the steel to change of fillet radius.

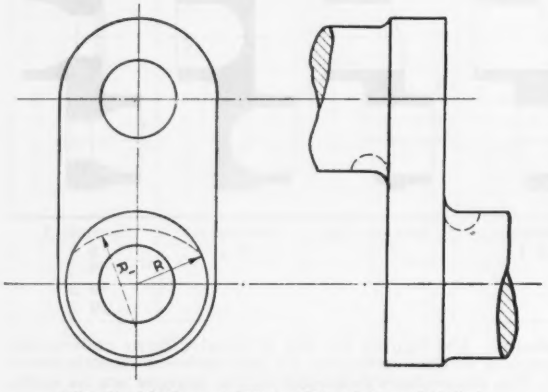


Fig. 8—Undercut fillets (Dietrich and Lehr)

For cast crankshafts, therefore, an increase of strength may be expected from an increase of fillet radius, and this increase will be greater the greater is the notch sensitivity of the material. It can also be expected that when the fillet becomes big a further increase of radius will bring a further change of strength comparable with the change found in a forged steel crankshaft, because in the range of the big fillets the notch effect of the cast iron will become less apparent and the general shape effect of the fillet will predominate.

Special Fillets

Where it is desired to increase the journal bearing area and at the same time retain the advantages of a large fillet radius it is possible to undercut the fillet into the web face.[30, 75] However, there does not appear to be any fatigue-test data to show how the strength of the shaft is affected by this procedure.

Another type of undercut fillet, this time undercut into the journal as illustrated in Fig. 8, was shown by Dietrich and Lehr[105] to reduce the maximum crankshaft stresses by 32%, under conditions of combined bending and twisting. A fillet of this type has been used for forged crankshafts.[106]

Reference has also been made to "compound" fillets for reducing stress.[57, 75] These fillets involve the use of a large radius blending into a smaller radius.

JOURNAL BORES

The advantages in respect of torsional strength of using journal bores can be seen from Figs. 2 and 7, and fatigue tests and stress measurements[104, 107] show that some increase of bending strength can also be obtained by this means.

For each application there is presumably an optimum size of journal bore for the achievement of increased crankshaft strength, but the various investigators do not appear to have given this point very much attention. Bandow[49] states that the ratio of bore to journal diameter should not be more than 0·5.

Apart from altering crankshaft strength, the introduction of lightening holes will affect the vibration characteristics of the crankshaft, since the inertia of the shaft is reduced and, presumably, the flexibility

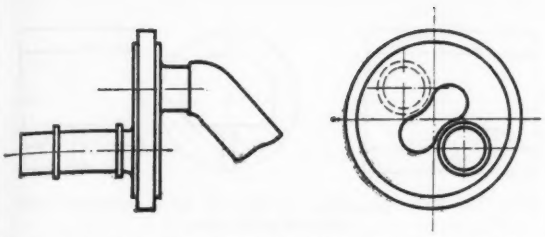


Fig. 9—Design for railway-engine steel crankshafts (Frémont)

of the crankshaft is increased. Smith[30] states that the use of hollow crankpins increases the single-node frequency of an engine by about 4% above that of a similar engine having solid crankpins.

Smith remarks that it is usual to bore the crankpin holes slightly offset away from the axis of the crankshaft by about 0·02 of the crankpin diameter. This has the effect of strengthening the crankshaft at the fillet and in addition further reduces the moment of inertia of the crankshaft.

Special-Shaped Bores

Lürenbaum[48] shows that the use of what is sometimes called a "barrel shaped" bore (illustrated in section *f*, Fig. 7) may considerably increase the torsional fatigue strength of steel crankshafts. It is seen that the barrel-shaped bore improves the torsional fatigue strength of the crankthrow over that obtained with the parallel bore by 65% for web-form *A*, by 25% for web-form *B*, by 19% for web-form *C*, and by 11% for web-form *D*. Oldberg and Lipson[107] found that the maximum bending stresses were about 15% lower with a barrel-shaped bore than with a parallel bore of slightly smaller diameter. The improvement in torsional stresses was much less.

The special crankshaft bore illustrated in section *e* of Fig. 7 is shown by Lürenbaum to be very advantageous in respect of crankshaft torsional strength, and this type of bore has been applied to the crankshaft shown in Fig. 19.

An illustration given by Johnstone and reproduced in Fig. 17 shows the use of a parallel bore with well-rounded ends.[102]

CRANKWEB PROPORTIONS

As shown in Fig. 7, increases of crankweb breadth considerably increase the limiting crankshaft torques. Mickel's tests (*see* Fig. 2) also reveal an increase of torsional strength with increase of web breadth.[47] Wedemeyer[108] points to the advantage of the high torsional rigidity obtained with circular webs.

There does not appear to be much information in respect of crankweb thickness (*i.e.*, the dimension parallel to the crankshaft axis) and torsional strength. However, if crankshafts of forms *A* and *D* of Fig. 5 are compared it will be seen that an increase of crankweb thickness of 25% and an increase of crankweb breadth of 17% together produce an increase of torsional strength (*see* Table X) of about only 5%.

Gadd[104] has shown that, in bending, an increase of web thickness from $\frac{3}{4}$ in. to 1 in. on a crankshaft of 3-in. dia. main journal reduces the crankshaft stress by 43%. A comparison of the bending fatigue values given in Table X for the web forms *A* and *D* of Fig. 5 shows that the increase of web thickness and the smaller increase of web breadth together produce a very small increase of limiting web stress, but since web-form *A* has a larger section modulus than that of web-form *D* this small increase of limiting stress represents a considerable increase of crankweb strength.

Various authors refer to the desirability of using the oval web form for obtaining good crankshaft stiffness, strength and efficient use of the material.[83, 108]

Special Web Shapes

In a design of crankshaft suggested by him for use in railway engines, Frémont[79] utilized crankwebs with holes through the centre, similar to that shown in Fig. 9. Forged crankshafts of the design illustrated were found to have considerably better service lives than crankshafts with the plain circular web, and among these successful crankshafts were some which

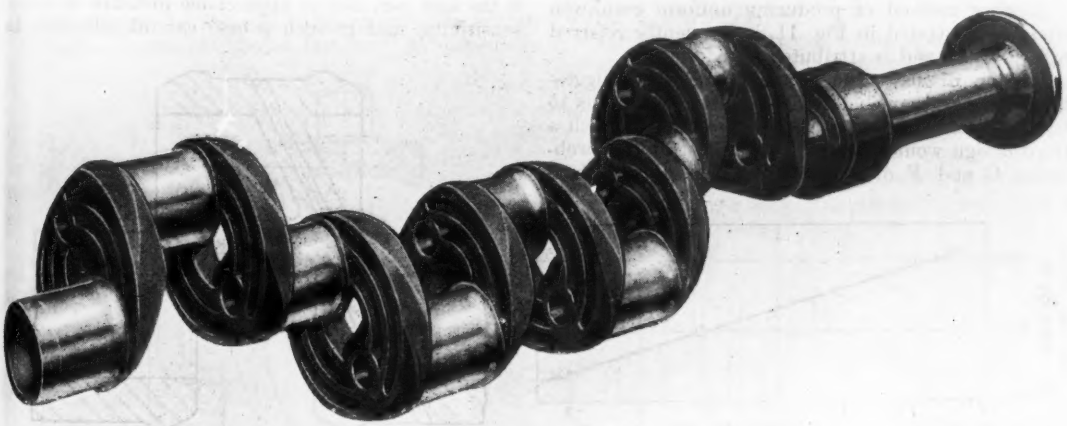


Fig. 10—Aero-engine cast crankshaft tested by Lürenbaum. The photograph has been retouched

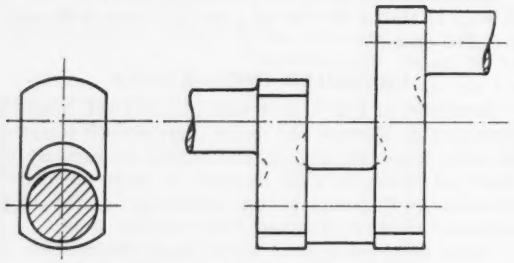


Fig. 11—Crankweb design (Klose)

had been machined to the new design after cracks had formed in service at the highly stressed centre of the web.[109] The better life of these crankshafts was attributed to two factors, namely, the stress-relief feature and the fact that the material removed in producing the design shown was of inferior quality, being developed from near the centre-line of the original ingot. Cast steel crankshafts of this design were later made for the French railways.[10]

Crankshaft designs of the Frémont type tested by Bandow are illustrated in Fig. 5, and the test results are given in Table X. In torsion, the Frémont designs are seen to be appreciably weaker than the conventional webs, while in bending the Frémont design is of about the same strength as that of the conventional web, revealing no advantage for the former design. Lürenbaum[48] carried out a test with an aero-engine using a cast crankshaft of the Frémont type, shown in Fig. 10. This crankshaft failed after about 90 hr. Torsional vibration measurements revealed that during running the crankshaft was being subjected to an alternating torsional stress of about 2·5 tons/sq. in., and tests subsequently carried out on undamaged throws of the crankshaft revealed that the limiting torsional strength of the crankshaft was of this order.

Bandow considers that the Frémont design will perhaps be of some advantage in those crankshafts in which the crank radius is very big in relation to the journal diameters.

Another method of producing uniform crankweb stresses, illustrated in Fig. 11, is frequently referred to[49, 57, 75, 108] and is attributed to Klose.[110]

Bandow discusses the Frémont and Klose suggestions fully and concludes that a better method is to have something between these two designs. Such a third design would be of the type illustrated in web-forms *C* and *F* of Fig. 5. This design, which is

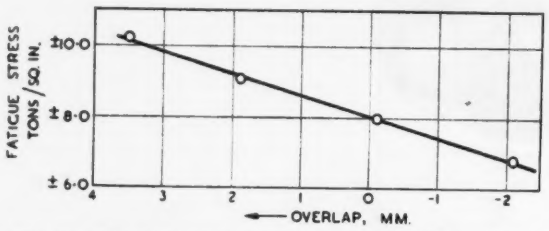


Fig. 12—Effect of overlap on crankshaft bending fatigue strength (Williams and Brown)

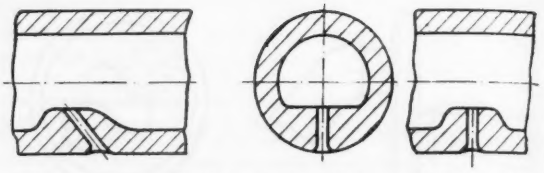


Fig. 13—Strengthening at the oil bore possible with cast crankshafts

apparently attributed to Bergmann,[49] utilizes a depression in the crankweb face, providing a well-rounded transition from the journal to the web, as in the Klose design, and stiffening up the outside of the web in relation to the centre, after the Frémont fashion. The results of Bandow's tests, as seen in Table X, however, reveal that in both bending and torsion the new design is only slightly stronger than the conventional web, and Bandow concludes that, for maxima of both bending and torsional strength, crankwebs should be made wide and relieved at the centre.

JOURNAL OVERLAP

A good feature of crankshaft design is obtained when the crank radius is small in relation to the diameters of the main journal and crankpin so that there is an overlap of the crankpin and the main journal.[49, 57, 83] It is obvious that by this means the critical section of the crankweb can be considerably increased without causing any increase of crankshaft length.

The big advantage of journal overlap in respect of bending strength can be seen from the results of tests carried out by Williams and Brown[33] on forged crankshafts. Different journal overlaps were produced by machining the journals of the standard shaft by a small amount. The results of the tests are given in Fig. 12. The 3½-mm. overlap corresponds to the standard shaft.

OIL BORE

With cast iron crankshafts the effect of the oil bore on fatigue strength will presumably become important if the cast iron has an appreciable measure of notch sensitivity, and in such a case careful attention to

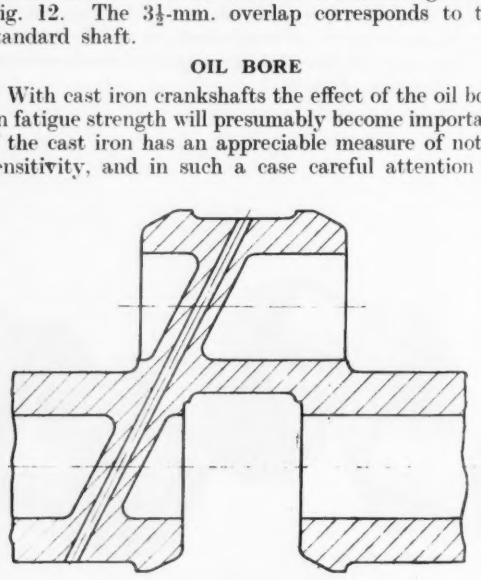


Fig. 14—Oil-bore arrangement possible with cast crankshafts

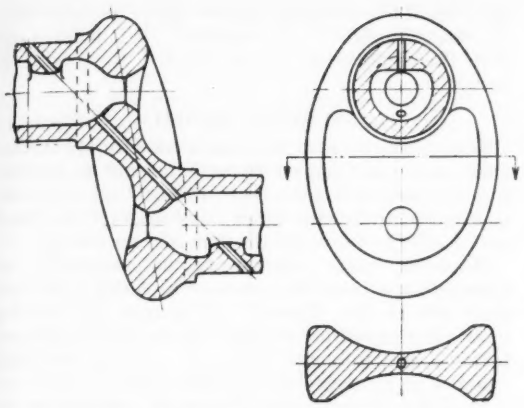


Fig. 15—Martinaglia's " ideal " cast-crankshaft design

oil-bore design, as is desirable with steel,[28] (*loc. cit.*, p. 524) will be well worth while. The results of Bandow's tests (*see* page 260) indicate that the malleable-iron crankshaft suffers about the same percentage reduction of torsional strength owing to the presence of a transverse bore as does the steel crankshaft. It is interesting to note also that the flame hardening of the malleable iron completely offsets the harmful effect of the oil bore.

It is said that the cast crankshaft may be strengthened in the region of the oil bore by using bosses as illustrated in Figs. 13 and 14.[57]

Wilson[31] points out that it is preferable to drill oil holes radially rather than diagonally through the journal wall, as experience has shown that there is more danger of torsional fatigue failure with the diagonal holes. In highly stressed shafts with hollow journals, that is with steel shafts at least, it is advisable to radius the inner as well as the outer edge of the oil hole.

A recent development described by Templeton[5] involves the incorporation of steel oil tubes in the crankshaft during the casting process.

SPECIAL CAST-CRANKSHAFT DESIGNS

Subsequent to his investigation on the fatigue strength of cast crankshafts, Bandow[49] developed the

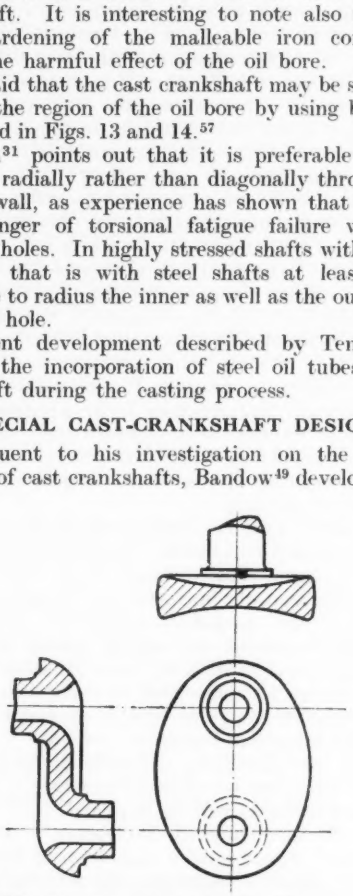


Fig. 16—Crankshaft design (Thum)

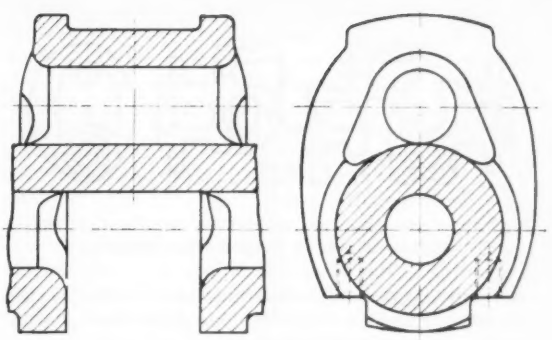


Fig. 17—Cast crankshaft (Johnstone)

cast-crankshaft design shown in Fig. 6. The main dimensions of this crankshaft were chosen to correspond to those of the crankshaft used for the tests described in Table VIII. However, the original narrow webs were widened to take a circular form, and a special peripheral reinforcement was added, thus increasing the thickness of the web. The peripheral reinforcement was designed so as to clear the connecting rods and crankcase during engine operation, but was interrupted in its circumference, as shown, in order that the shaft could be fitted in its bearings; the reinforcing rims actually overlapped the ends of the bearings. It can be seen that the stress-relieving web depressions and barrel-shaped bores are also used. It is obvious that this design involved a considerable increase of crankshaft weight.

A crankshaft of the new design was made using high-carbon cast steel, and the good fatigue-test results for this shaft can be seen from the fatigue-test data given on page 265. The torsional fatigue strength of the new design is somewhat greater than that of the steel crankshaft of the original design, as seen from Table VIII. The limiting bending fatigue stress for the new design is also greater than that of the steel crankshaft, and if the crankshafts are compared on the basis of limiting bending moment (that is absolute bending strength) the cast crankshaft is far superior to the forged steel one.

Martinaglia[57] illustrates what he describes as an ideal shape for a cast crankshaft. This is shown in Fig. 15. Here the web depressions, barrel-shaped bores, and oil bosses are used, together with a shaping of the outside of the web to reduce weight.

The design shown in Fig. 16 is considered by Thum[103, 111] to give a suitable distribution of crankshaft stresses. This crankthrow, which has an

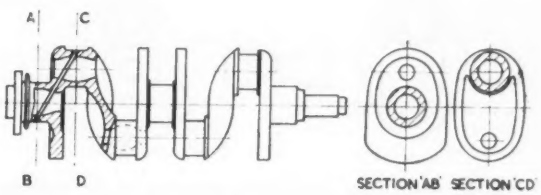


Fig. 18—Cast crankshaft tested by Siebel and Stähli

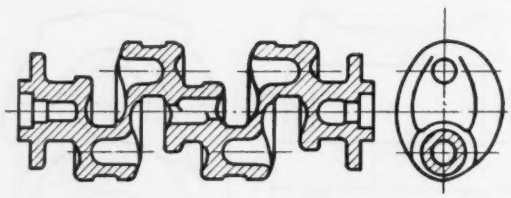


Fig. 19—Cast iron crankshaft of high-speed Diesel engine of small output (Martinaglia)

unusually large crank radius in relation to the journal diameter, employs the web depressions and journal bores with well-rounded edges.

In Fig. 17 is seen a design for a cast crankshaft which has main journals and crankpins of $7\frac{1}{4}$ in. dia. and a very large journal overlap, and which incorporates web depressions and journal bores with well-rounded ends.[102]

A cast crankshaft tested by Siebel and Stähli[61] is shown in Fig. 18. In the engine-type test-rig used by these investigators, high torsional and bending loads were produced by heavy pistons through connecting rods applied to the crankpins of the motored crankshaft. Cast crankshafts of the design shown were compared with forged steel crankshafts of a different crankweb and journal-bore design, but of the same general dimensions. Under these conditions the forged shafts were seen to be superior in strength to the cast shafts, but the amount of superiority of the forged shafts was not indicated.

In a cast crankshaft referred to by Jungbluth[56] both the webs and the journals are cored, leaving the crankshaft as a very thin-walled shell.

Some interesting cast-crankshaft designs given by Martinaglia[57] are shown in Figs. 19 and 20.

An interesting feature of design patented by Messrs. Sulzer Frères, S.A., consists of the use of metal inserts cast into the crankweb.[112] The metal inserts may themselves be forged or cast. It is suggested that by this method the web can be reinforced, the stress distribution in the web being rearranged in such a way as to lead to increased strength. To do this, presumably the metal insert must be made of a material of considerably greater elastic modulus than the cast material of the crankshaft. It is pointed out that this innovation is not limited to crankshaft design.

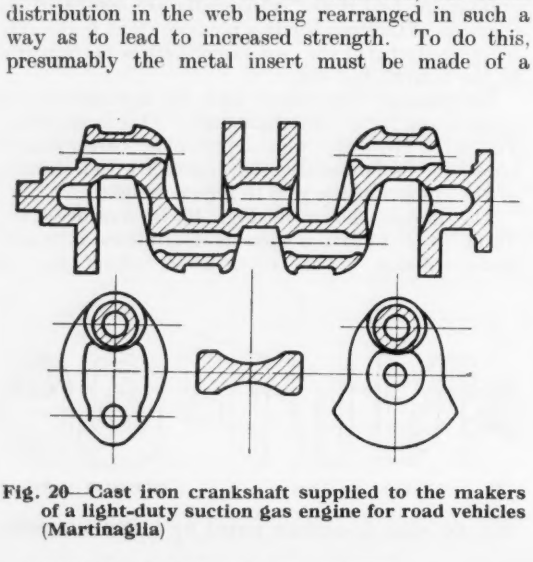


Fig. 20—Cast iron crankshaft supplied to the makers of a light-duty suction gas engine for road vehicles (Martinaglia)

SURFACE FINISH

With cast irons of low notch sensitivity, surface finish would not appear to be important in relation to crankshaft strength. One author[53] refers to this and states that with large crankshafts it is found practicable to eliminate the grinding operation.

However, there appears to be practically no information to show how the surface finish of the cast shaft affects the character of journal and bearing wear. Templeton[5] states that after a short running-in period a cast iron shaft takes on a mirror-like finish which is highly resistant to further wear.

It is stated in one case that slight porosity on the bearing surfaces of a cast crankshaft did not reduce the bearing qualities.[60]

DESIGN IN RELATION TO CRANKSHAFT STIFFNESS, WEIGHT, INERTIA, AND COST

In the foregoing the various features of design have been considered mainly in relation to crankshaft strength, but in practice the introduction of a particular design feature must be considered in the light of various other factors as well. Points to consider are (1) the cost of introduction of the particular feature of design, (2) the effect on torsional stiffness and inertia, or, in other words, the torsional vibration properties of the crankshaft, (3) the effect on bending stiffness, and (4) the effect on crankshaft weight.

It is considered by one author[83] that at present there is insufficient evidence to confirm that the increase in fatigue strength to be obtained by using the special cast-crankshaft shapes is large enough to warrant the extra trouble and expense that would be incurred. When changing from a forged steel to a cast crankshaft only those changes in design that are possible without difficulty and additional cost should be made.[53, 60] In this connection, Templeton[5] considers that in practice the introduction of the special design features does incur additional cost in the case of crankshafts of comparatively simple form, but does not do so where the general conditions of design necessitate the use of the vertical core assembly method of moulding.

The use of balance weights, which are easily incorporated in cast crankshafts, has obvious advantages, but here again disadvantages may arise. Peirce[34] has shown that the introduction of balance weights to a particular crankshaft reduced the bearing loads but also decreased the critical speeds of torsional vibration and increased the amplitudes of vibration. For this case he considered that the counterweights would lose their value unless accompanied by a torsional vibration damper.

Again, the chamfering of crankshaft webs to reduce weight must not be carried to excess, or crankshaft torsional stiffness will be impaired.[83, 113]

It will be remembered that Carter considers that a crankshaft should have a maximum of bending flexibility.[76] In this connection the remarks of Gadd[104] are of interest. He shows first, as noted earlier, that

crankshaft strength may be increased by increasing the crankweb thickness, or by boring the journals. He goes on to say that if, in attempting to choose the most favourable alternatives for increasing strength, it is assumed that the crankcase constrains the shafts to a certain extent from flexural distortion, an increase of fillet radius would be more advantageous than an increase of crankweb thickness, since the latter change, in stiffening the shaft, would allow a lesser proportion of the crankshaft loads to be transferred to the crankcase. It might be still better to use hollow journals and crankpins. Again, an increase of shaft stiffness, effected by thickening the crankwebs, might be desirable in order to move the torsional resonance speeds outside the running range.

PRODUCTION OF CAST CRANKSHAFTS

Founding

In this report it is not proposed to discuss the various aspects concerning foundry technique, since the casting process is essentially of a very specialized nature. The details of foundry technique will differ from foundry to foundry, with the type of material cast, and with the crankshaft design. However, it is considered desirable to make some reference to sources of information on this subject.

Details are given by Dwyer[13] of core manufacture and handling in the early Ford casting process. Cone[1] describes the early Ford technique of melting and moulding, and later[89] describes a new type of cupola for continuous melting and pouring of the crankshaft material. Johnstone[102] discusses the merits of the three distinct methods of casting large crankshafts, namely, (*a*) vertical pouring and vertical cooling, (*b*) horizontal pouring and horizontal cooling, and (*c*) horizontal pouring and vertical cooling, and he goes on to give the founding details for a crankshaft of $7\frac{1}{4}$ in. journal diameter. Geschelin[2] gives some details of mould production, and shows that in the production of large crankshafts at the foundry with which he is concerned the horizontal-pouring and vertical-cooling technique is used. Templeton[5] discusses the vertical- and horizontal-casting techniques and gives photographs of crankshafts cast by each of the two methods. Some details are given of the crankshaft-production technique at a foundry using chromium–molybdenum crankshaft iron.[59] It may be noted that Morris[114] makes a reference to the use of permanent moulds in the production of crankshafts.

Inspection

In addition to the usual foundry inspection methods, the use of X-ray examination may be of considerable value in bringing about increased confidence in the cast crankshaft. In some quarters there may be reluctance to assume that the crankshaft is perfectly sound and homogeneous, and X-ray examination will ensure that only sound castings are passed on to the engine builder. This type of inspection may also be of great use in the development of casting technique.[5]

At one American foundry each crankshaft design is said to be treated as an individual research problem, which is approached first on the basis of past experience and later modified from the results of X-ray studies of the castings.[2] Vennerholm[84] points out that the use of the tank-engine nitrided cast steel crankshaft, mentioned earlier, was made possible not only through the careful selection of material and careful design, but also through the rigid control of manufacturing procedures and utilization of X-ray and "Magnaflux" inspection for the elimination of defective castings.

Templeton[5] observes that the results of the X-ray examination may, however, be difficult to interpret. For example, the crankshaft which was described earlier in this report as having run very successfully in an engine at an overload of 50% increase in piston loading was one which showed signs of porosity under X-ray examination.

Machining

As mentioned already, it is possible to produce the cast crankshaft in such a way that all machining of webs, counterweights, and journal bores is eliminated. The casting length can be held to within $\frac{1}{32}$ in. on small and medium shafts, and the taper on vertical faces in the mould is negligible. Many cast shafts of up to 4 ft. in length have been produced with machining only on the journals and with a clearance of $\frac{1}{32}$ in. between the bearing-location faces and the face of the web. The machining allowance on the journals of small shafts can be $\frac{1}{16}$ in. on radius, and the ideal is to cast to a grinding allowance, which is by no means impracticable. With increasing size of the shaft it is usual to allow $\frac{3}{16}$–$\frac{1}{4}$ in. for machining. Distortion in the casting is rare and need not be considered in determining machining allowances.[5]

Some details are given of the machining of high-carbon cast steel automobile crankshafts;[66,115] details may be obtained of the machining of some acicular-iron crankshafts,[99] and Bergdoll[19] gives some photographs illustrating the machining of some inoculated-iron shafts.

SPECIAL PROCESSES

Apart from the normal heat-treatments associated with the production of some of the cast crankshaft materials, there are special additional processes which may be employed. These may be arranged under the headings of special heat-treatments and surface treatments.

It is clear that the employment of a special process, at extra cost, must be avoided unless the process is one which will give the cast crankshaft greatly improved properties.

Heat-Treatment

Eagan[97] has investigated the effect of various heat-treatments on some inoculated crankshaft iron. He found that by using certain heating cycles the tensile strength of one iron could be improved considerably above that for the as-cast state, but the corresponding bending fatigue strength of the iron was not increased to the same extent. In one case there was no increase of bending fatigue strength accompanying the increase of tensile strength. With another iron of this type

considerable increases in tensile strength could again be obtained, but in some cases these were accompanied by decreases in the fatigue strength. Presumably the irons attaining high tensile strength would also suffer an increase of notch sensitivity.

Geiger[70] investigated the torsional fatigue properties of two malleable crankshaft irons which had been hardened by heat-treatment. He found that the increases of unnotched fatigue strength for the hardened bar over the unhardened bar were, respectively, 72% and 43% for the two irons. For notched hardened bars the corresponding increases of strength over the notched unhardened bars were 12% and 11%. These results indicate both an increase of endurance limit and an increase of notch sensitivity accompanying the increase of tensile strength.

It is of interest to note that Lürenbaum[48] investigated the effect of heat-treatment on the torsional fatigue strength of forged crankshafts. He found that the fatigue strength of the crankshafts changed roughly in proportion to the tensile strength of the materials, as obtained by heat-treatment.

Apart from the extra cost of heat-treatment, the danger of distortion is pointed out.[60]

Surface Treatments

It is stated, for some of the cast crankshaft materials at least, that the wear properties may be improved by chilling, or by flame or induction hardening the crankshaft journals.[54, 60, 95] In the case of blackheart malleable iron, it will be remembered, the wear properties are unsuitable unless such hardening is used. Tests on model crankthrows, described by Bandow and referred to on page 260, show that flame hardening improved the torsional fatigue strength of solid blackheart malleable crankthrows by 17% and improved the torsional fatigue strength of solid blackheart malleable crankthrows with transverse bores by 62%. However, it will be seen from Table VIII that the flame hardening of some pearlitic iron crankshafts reduced the torsional fatigue strength by 17%.

The pearlitic malleable irons are said to be more adaptable to flame or induction hardening than is standard malleable iron.[90]

In connection with the surface-hardening processes the danger of cracking is pointed out.[60]

It is of particular interest to note that the fatigue strength of malleable-iron parts is said to be increased by shot-blasting or cold-working the highly stressed areas.[90] It is well known that these processes are effective in improving the fatigue strength of forged crankshafts.[52, 116] Bandow,[49] however, considers that a raising of the endurance strength by this means cannot be expected with cast crankshafts, because, in general, the cast materials do not possess the necessary ductility. Presumably this applies only to the more brittle cast materials.

Reference has been made earlier to a nitrided cast steel crankshaft.[84] It would be of great interest to know how the nitriding affects the strength of the cast steel, and to discover whether it would be possible to use nitrided cast iron crankshafts. With forged steel crankshafts nitriding not only improves the wear properties, but has also been shown to give a great increase of crankshaft bending fatigue strength.[33, 116]

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Magnetic Concentration Experiments Upon Iron Ores Used In North Lincolnshire Practice

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SYNOPSIS

This paper is essentially an introductory one to place on record the programme of work now being carried out at the Appleby-Frodingham Steel Co. on the magnetic concentration of low-grade iron ores used in North Lincolnshire ironmaking practice. Preliminary laboratory experiments, in 1944, indicated that promising results might be obtained by a magnetic roast of Frodingham calcareous ores followed by magnetic concentration. The preliminary results with Northamptonshire siliceous ores were not so encouraging.

It was decided that the results with the Frodingham ores justified the design and installation of a small magnetic roasting kiln, approximately 23 ft. in length and 2 ft. 8 in. in diameter, to determine to what extent the laboratory results could be duplicated on a somewhat larger scale. Full details of this kiln, together with those of a continuous magnetic separator of the Ball-Norton belt type are given. Preliminary results indicate that the kiln fully confirms the laboratory results through a wide range of ore feed and gas flow.

Some consideration is also given to the use of suitable factors to express degree of concentration achieved, examples of which are given. The importance of the petrographic structure of iron ores in relation to their concentration is also indicated.

It is probably true to say that ores used in North Lincolnshire iron-smelting practice have a lower average iron content than any ores smelted commercially in the rest of the world. They consist of a mixture of Frodingham limey ores averaging, as mined, about 21% of Fe and 21% of CaO, and siliceous Northants ores averaging about 33% of Fe and 13% of SiO_2, the ratios in which they are used giving a self-fluxing burden, including sinter, averaging about 29% of Fe.

Extensive physical preparation of the ores is carried out at Appleby-Frodingham as described in *Iron and Steel Institute*, 1944, *Special Report No.* 30. Crushing, screening, and bedding assists in putting the ores into suitable sizes, and mixes them sufficiently to overcome local burden variation. Sintering of the fines is also carried out extensively. Initially introduced as a means of disposing of the fines produced during crushing, good strong sinter is known also to benefit the working of the blast-furnaces and must be regarded as a means of beneficiating iron ores.

The result of this considerable preparation of ores has been to improve, very appreciably, the output and fuel consumption of Lincolnshire furnaces, despite the handicaps involved by the large slag bulk per ton of iron—average 25 cwt./ton—and the high ore/coke ratio inherent in the low average iron content of the burdens.

None of the methods of ore beneficiation at present in use has led to reduction in the slag bulk per ton of iron produced, and in this sense none of them can be classed as true concentration methods; even in sintering, which leads to an apparent concentration of iron owing to the loss of volatile constituents, *viz.*, moisture and carbon dioxide, the slag bulk is not decreased per unit of iron. Nevertheless, although no true iron-concentration processes have yet been introduced into Appleby-Frodingham practice, a good deal of investigation of the problem on a laboratory scale has been proceeding for several years, and in the case of one process, *viz.*, concentration after magnetic roasting, has attained the stage of small-scale pilot-plant investigation.

It is the purpose of this short report to give a general indication of the progress which has been made in magnetic concentration of these low-grade ores, and to describe briefly a pilot-plant kiln and magnetic separator. Insufficient work has been completed to justify a fuller report, but it was thought worth while to place on record the general progress of the work to date, if only to avoid duplication by other investigators.

PRELIMINARY INVESTIGATIONS

Some preliminary investigation on Lincolnshire ores was carried out as far back as 1935. Without going into detail, it can be stated that wet-washing methods were examined, but the results were not sufficiently promising to warrant practical application. The problem was re-opened by the author just before the last war, but detailed laboratory work could not be started until February, 1944. Briefly, it was found that magnetic roasting of calcareous Frodingham ores could be carried out at temperatures as low as 500° C. in a controlled, slightly reducing, atmosphere, to give a product which could be divided magnetically into concentrate, middlings, and tailings, the proportions depending upon the magnetic system used. The methods used have been described in numerous publications.[1–4]

Preliminary laboratory experiments were promising, as the following sample results show:

	Ore 1 (Thealby Rough), %	Ore 2 (Winns Wing Ironstone), %	Ore 3 (Thealby Rough Ironstone), %
Fe content as received	25·9	18·9	21·8
Fe content after concentration	49·8	39·7	41·2
Fe recovery	86·1	76·2*	72·4*

* Excluding middlings

The middlings from ore 3 were reconcentrated, giving a final iron concentrate as follows:

Fe content of concentrate	41·1%
Percentage of iron recovered	85·3%

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A more detailed chemical analysis and balance sheet of ore concentrate, middlings, and tailings, using a mixture of seven local ores, is shown in Table I.

It will be noted from column 5 that 76% of the tailings consist of $CaCO_3$, largely as free calcite, and the concentration process consists essentially of a removal of excess calcite from the ore, leaving it very much nearer a self-fluxing condition than was the original ore ; note in this connection the ratio of CaO to SiO_2 in ore and concentrate.

Concentration Factor

It is convenient at this point to introduce a suitable factor to express the degree of concentration of a given ore and to compare the concentration achieved using different types of ores. Several expressions are possible but the following is the more convenient :

$$\frac{\%\ \text{Fe in concentrate}}{\%\ \text{Fe in original ore}} \times \%\ \text{Fe recovery} \quad \ldots\ldots(1)$$

In practice, however, this simple expression comes up against the fact, already mentioned, that an apparent increase in iron content may be achieved purely as a result of loss of volatile constituents (carbon dioxide and moisture) without any reduction in slag-forming constituents. This may be met by modifying the expression to :

$$\frac{\%\ \text{Fe in concentrate (calcined)}}{\%\ \text{Fe in original ore (calcined)}} \times \%\ \text{Fe recovery} \quad (2)$$

The iron (calcined) may be determined for both concentrate and original ore by applying a correction for their loss on ignition, under oxidizing conditions ; the latter qualification is important to prevent complications due to ferrous iron. This factor might be called the "Concentration Efficiency Factor". It will be noted that it assumes that degree of concentration and iron recovery are of equal importance.

Alternatively, the reduction in slag-forming constituents achieved by a concentration process may be assessed by calculating, for both concentrate and original ore, the following expression :

$$\frac{\%\ SiO_2 + \%\ CaO + \%\ Al_2O_3 + \%\ MnO^* + \%\ MgO}{\%\ Fe} \quad (3)$$

i.e., the approximate weight of slag-forming constituents per unit of iron. Such an expression, however, does not give the true slag bulk since in practice either SiO_2- or CaO-bearing materials might have to be added to produce the desired slag composition ; nevertheless, the factor is useful for comparative purposes when dealing with ores of a similar type. It might be referred to as the "Slag Ratio Factor".

For the degree of concentration achieved in Table I these factors work out as follows :

Concentration Factor Number	Original Ore	Concentrate Only	Concentrate + Middlings
2	...	$\frac{46{\cdot}4}{28{\cdot}5} \times 76{\cdot}2 = 124$	$\frac{40{\cdot}7}{28{\cdot}5} \times 89{\cdot}8 = 126$
3	1·54	0·65	0·92

It is interesting to note that according to factor No. 2 there is little difference in the degree of concentration achieved in concentrate alone, and in the concentrate plus middlings. The improvement in iron recovery obtained by adding the middlings to the concentrate (from 76·2 to 89·8%) has been counteracted by a reduction in the average iron percentage from 46·4% in concentrate alone, to 40·7% in concentrate plus middlings—both cases corrected for loss on ignition. Concentration factor No. 3, which expresses the approximate slag bulk per unit of iron, shows that in the original ore this was as high as 1·54 (*i.e.*, 30·8 cwt. slag-forming

* Strictly speaking, only a proportion of the MnO should be included, as part of it is reduced into the metal.

Table I

MAGNETIC CONCENTRATION RESULTS FOR BEDDED LOCAL ORE

	Weight, %	Fe Content, %	Fe Recovery, % of Total
Original ore	108·8*	23·6	...
Ore after roast	100·0	25·04	100·0
Concentrate	45·82	41·8	76·47
Middlings	17·79	18·8	13·36
Tailings	36·39	7·0	10·17

CHEMICAL ANALYSIS FOR BEDDED LOCAL ORE

	(1) Original Ore	(2) Ore after Reduction	(3) Concentrate	(4) Middlings	(5) Tailings	(6) Concentrate + Middlings	Recovery, %	
							Concentrate + Middlings	Tailings
Fe, %	23·6	25·04	41·80	18·80	7·0	35·37	89·83	10·17
SiO_2, %	6·78	6·95	7·76	9·55	4·66	8·26	75·6	24·40
CaO, %	22·90	26·14	11·40	28·40	43·60	16·15	39·3	60·70
Al_2O_3, %	3·94	4·07	4·75	5·12	2·70	4·85	75·86	24·14
MnO, %	1·45	1·70	1·75	1·95	1·52	1·81	67·46	32·54
MgO, %	1·26	1·28	1·55	1·30	0·93	1·48	73·56	26·44
Loss on ignition, % †	26·44	20·32	9·79	21·85	32·82	13·16	...	...

* Calculated on the basis of the roasted ore as 100%. † Mainly CO_2

materials per ton of iron); it falls to 0·65 (13 cwt. per ton) in the concentrate and rises again to 0·92 (18·4 cwt. per ton) when the middlings are added.

It must be pointed out, again, that these are only rough measures of the slag bulk which would be attained in practice. Thus the actual slag bulk attained, using a mixture of 45% of local ore, 30% of Northants ore, and 25% of sinter is about 25 cwt. per ton of pig, which would be reduced to 13·7 cwt. using concentrate alone. In both cases allowance has been made for coke ash. It should be noted that concentration factor No. 3, *i.e.*, the Slag Ratio Factor, does not allow for percentage iron recoveries.

It is too early, yet, to say which of these concentration factors is likely to be the more useful, and the above discussion is intended only to stimulate further study of the matter.

Northants Ores

As already indicated the Northants ores are normally more siliceous than those in the Frodingham beds. Silica may be present in the free form but it is more usually combined with the iron as an iron-aluminium-silicate known as chamosite. It should be pointed out that chamosite is also present in some of the Frodingham ores, but not to the same extent as in many of the Northants ores.

Detailed geological and petrographic study of these ores, both before and after concentration, is now under way, and it should be possible finally from the petrographic structures to predict to some extent the probable degree of concentration which an ore will undergo. Figure 1 shows the microstructure of a thin section of a highly calcareous Frodingham ore, provisionally referred to as type D, which is similar to those used in tests 1 and 3.

The ooliths are essentially limonite, sometimes accompanied by chamosite, which, together with some siderite and massive calcite fossil remains, are embedded in a matrix which is essentially calcite. Physical separation of the calcite from the iron-bearing

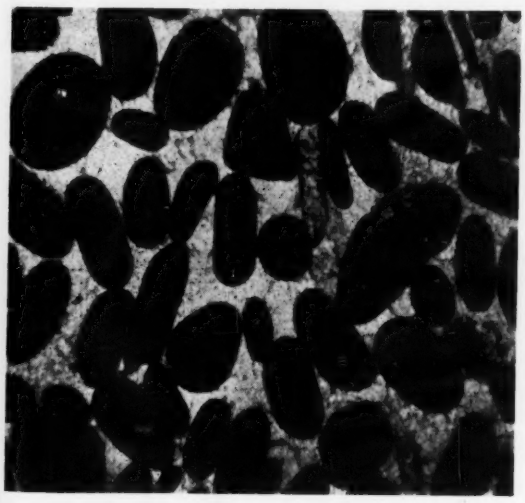

Fig. 1—Thin section of Frodingham Ore. Type D × 40

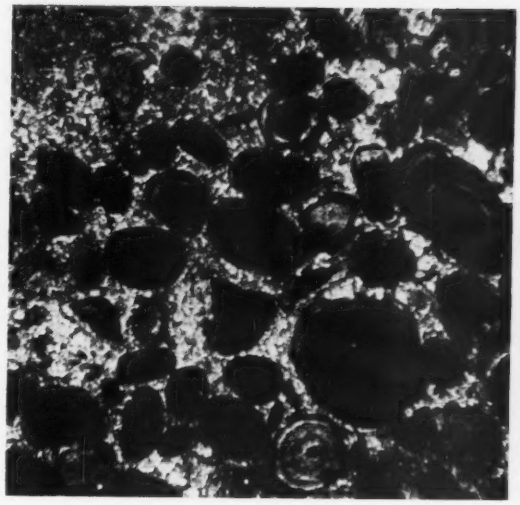

Fig. 2—Thin section of Northants Ore. Type X × 40

constituents limonite and siderite is a relatively simple matter with such a structure. On the other hand, a typical Northants ore is shown in Fig. 2, which is a thin section of an ore provisionally referred to as type X, consisting of chamosite ooliths in a matrix of siderite. The main slag-forming constituents, SiO_2 and Al_2O_3, are chemically combined with the iron in the chamosite and separation by simple physical means is impossible. This type of ore on weathering gives an intimate mixture of limonite and iron-free clay and presents somewhat similar difficulties to separation by physical means. As a result, magnetic treatment of Northants ores gives, in most cases, little true concentration, much of the apparent increase in iron being due to loss of volatiles. This is shown in the following results:

Ore B (Colsterworth No. 2–Green Carbonate Ore)

Fe as received	36·5%
Fe after magnetic roast	44·6%

Crushed to 30 mesh and submitted to magnetic treatment, with the following results:

	Fraction Weight	Fe, %	Fe Recovery, %
Concentrate	91·2	46·2	94·3
Tailings	8·8	29·0	5·7

$$\text{Concentration Factor } \frac{46\cdot2}{44\cdot6} \times 94\cdot3 = 97\cdot6$$

Ore A (Colsterworth North–Brown Weathered Ore)

Fe as received	43·8%
Fe after magnetic roast	54·2%

Crushed to 30 mesh and submitted to magnetic treatment:

	Fraction Weight	Fe, %	Fe Recovery, %
Concentrate	92·6	56·2	95·9
Middlings	6·6	33·6	4·0
Tailings	0·8	5·6	0·1

$$\text{Concentration Factor } \frac{56\cdot2}{54\cdot2} \times 95\cdot9 = 99\cdot4$$

It will be noted that the effect of the magnetic roast is to produce a product with very little non-

magnetic tailing; or rather the non-magnetic tailing is so intimately associated with the magnetic constituents that they cannot be separated with the equipment available. Thus, there is little true concentration in these ores, as indicated by the concentration factor being very near 100. Further work upon Northants ores is proceeding however and it is hoped that suitable conditions may be found to improve upon these results.

PILOT-PLANT MAGNETIC ROASTING KILN

The laboratory results obtained using the Frodingham ores were regarded as sufficiently promising to justify the installation of a small pilot plant (consisting of a rotary kiln and a continuous magnetic separator), to determine to what extent the results could be duplicated on a scale sufficiently large to justify more serious consideration. The equipment is shown in Figs. 3 and 4, and in the photograph, Fig. 5. Some points of detail are given below.

Details of Kiln

The kiln, Fig. 3, consists of a cylindrical steel shell approximately 23 ft. in length and 2 ft. 8 in. in dia., with a brick lining 4½ in. thick, reducing the internal diameter to 1 ft. 10 in. The furnace consists of two main sections, the longer of the two (A) being approximately 13 ft. in length and acting as the heating and reducing section. This section is also provided with four lifting vanes (V) which help to increase the contact between ore and gas. The shorter section (B) is approximately 9 ft. in length and acts as a cooling and oxidizing section. Air only enters this cooling section through an adjustable vent (L) in the discharge-end casing, the flow being controlled by a suction fan (M) and damper (O) leading to the exhaust flue (P). Firing is by blast-furnace gas fed through a 2-in. pipe (C), which projects into the firing zone at point (D) through the centre of a specially designed hematite iron burner ring (E).

The ore to be treated, previously crushed to — ⅝-in. size, is fed into the kiln through the main hopper, holding approximately 1 ton (F), into the secondary hopper (G), which is fitted with a worm feed (H) actuated by a ratchet (J), which is in turn controlled by the rotation of the kiln. Rate of feed can be varied between 1·33 cwt. and 11 cwt. of ore per hour. Speed of rotation of the kiln can be varied between 3 and 9 revolutions per minute and its slope may be altered between ½° and 4° by adjustable jacks and stops which support the base of the kiln. Discharge of the roasted product takes place at an automatic discharge door (K) into a small skip. The counterweights to the discharge door are controlled so that a minimum depth of ore of 18 in. is always present to act as a seal against excessive air infiltration. The gas flow to the kiln is controlled by a valve and flowmeter, the maximum gas pressure available at the entry being 6 in. Facilities have been provided to trap any coarse dust carried over in suitable dust legs. Temperatures in the kiln can be measured continuously during operation at four points along its length by means of four thermocouples (1, 2, 3, and 4 in Fig 3), which are in turn connected to a 4-point Cambridge indicator by means of the four slip rings clearly shown in Fig. 5.

Details of the Continuous Magnetic Separator

Careful consideration was given to various types of magnetic separators, of both the rotary and belt type. In view of the lack of practical experience with these ores it was finally decided to design a belt separator based on the Ball-Norton machine; not because this was necessarily the best type to use, but mainly because its operation was so easily adaptable to an experimental set-up. This separator is shown in Fig. 4. The gaps between the two belts and between the upper belt and the magnet poles are accurately adjustable, whilst the belt speeds are also adjustable. The current, which is D.C., is provided by a rectifier and is adjustable through a wide range. The 12 magnet pole pieces are arranged in such a manner that reversal of polarity occurs between each. This has the effect of causing the magnetic material held by the upper belt to turn through 180° at each pole face and so helps to shake loose any adherent non-magnetic tailings. The feed to the concentrator is *via* hopper (T) and hammer mill (U), which crushes the roasted ore to — $\frac{1}{32}$-in. mesh and drops it on to the lower feed belt (W).

The tailings remain on this belt and are carried

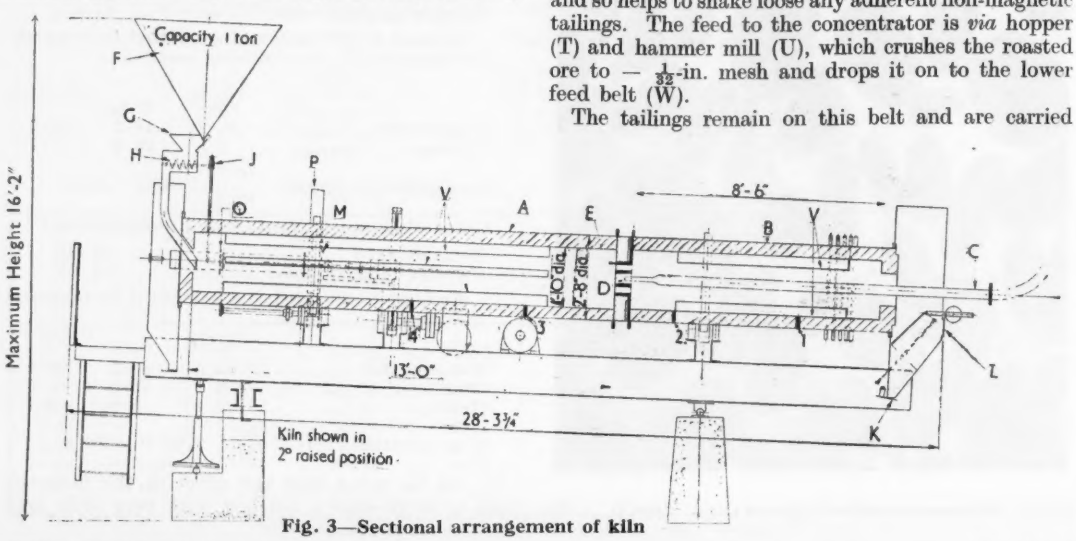

Fig. 3—Sectional arrangement of kiln

Table II

DATA FOR KILN AND MAGNETIC SEPARATOR

Kiln	
Overall length of kiln	28 ft. 3¾ in.
Diameter inside brickwork	22 in.
Thickness of firebrick	4½ in.
Length of roasting section	13 ft. 0 in.
Length of cooling section	8 ft. 6 in.
Size of ore feed	⅝ in.
Density	90 lb./cu. ft.
Wt. of ore in roasting zone (based on ⅓ full)	5¼ cwt.
Wt. of ore in cooling zone (based on ⅓ full)	3¾ cwt.
Speed of drum—variable	3 to 9 r.p.m.
Peripheral speed inside—variable	17 to 51 ft./min.
Kiln motor drive	5 h.p. at 730 r.p.m.
Roasting time for 2 cwt./hr.	About 3 hours
Inclination of drum, min.	½°
Inclination of drum, max.	4°
Blast-furnace gas to burner	2000 to 5000 cu. ft./hr.
Capacity of raw-material hopper	1 ton flush
Screw feed variable between	1·33 and 11 cwt./hr.
Magnetic Separator	
Fan motor	1 h.p. at 1430 r.p.m.
Capacity of skip hoist	2 cwt.
Capacity of hopper	1 ton flush
Capacity of crusher	5½ cwt./hr.
Crusher motor	5 h.p. at 730 r.p.m.
Separator motor	1 h.p. at 1420 r.p.m.
Normal speed of separator conveyors	25 ft./min.
Space between separator belts—variable between	¼ in. and 1½ in.
Power requirements of magnets	800 W.

over at point (Q) into the tailings bin (Z). The concentrate is attracted by the magnetic field and adheres to the lower face of the upper belt (X), from which it drops off at the last magnet (R) into a separate concentrate bin (S). A summary of technical data concerning kiln and separator is given in Table II.

DISCUSSION ON PRELIMINARY TRIALS

Sufficient tests have now been carried out with the above-described roasting kiln and magnetic separator to give a fairly clear indication of the results which can be obtained. The tests to date have been carried out on Frodingham ores only, and have shown that the equipment is flexible through a wide range of ore feed and gas flow and air/gas ratio, and that it gives a degree of concentration fully equal to that obtained in the small-scale laboratory tests. Iron recoveries as high as 93% have been attained with percentage iron in the tailings below 6%. Some typical results are reported in Table III, which were

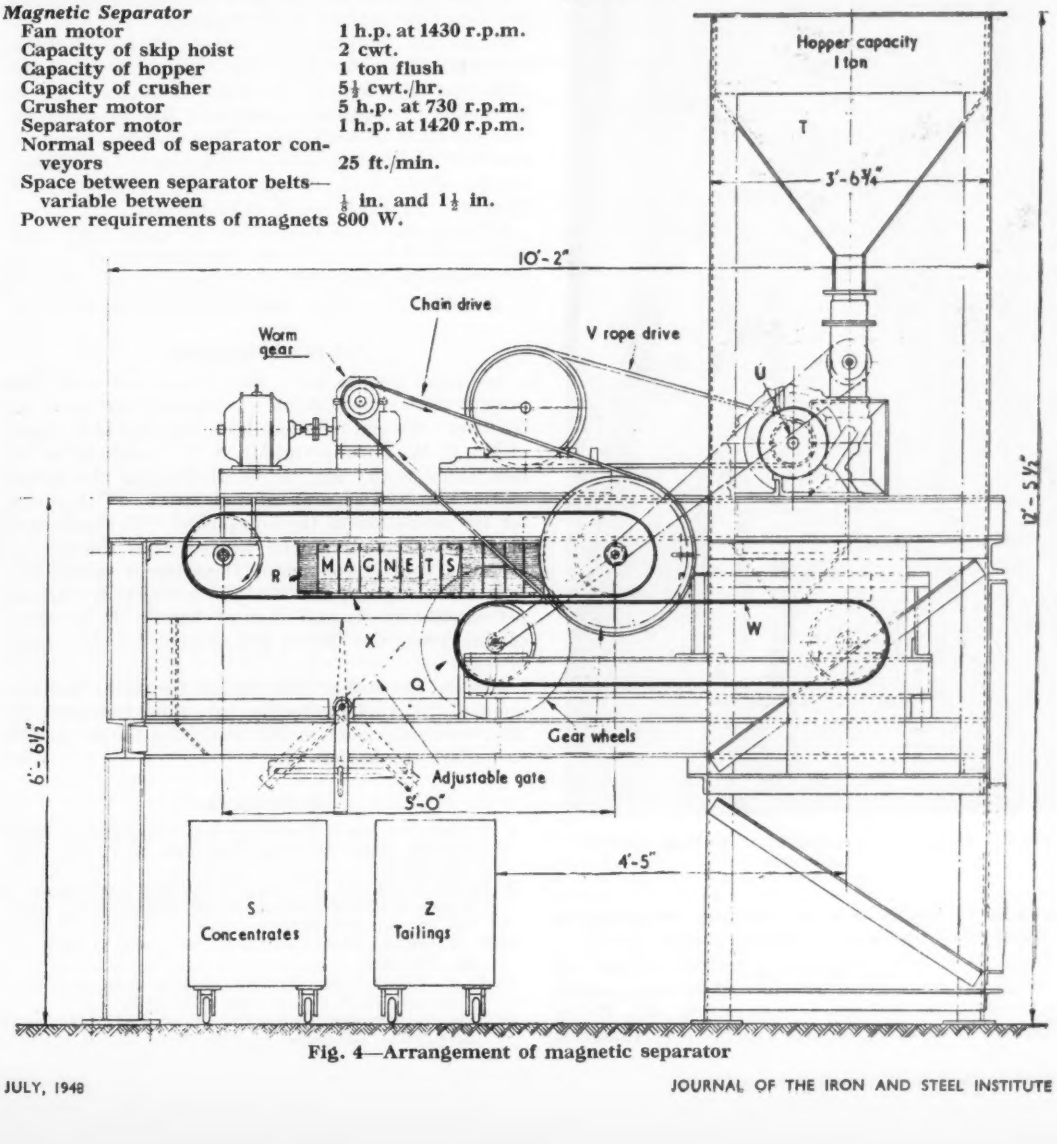

Fig. 4—Arrangement of magnetic separator

Table III

TYPICAL RESULTS GIVEN BY PILOT-PLANT KILN AND MAGNETIC SEPARATOR

Test No.	Raw Ore-Analysis, Dried at 100° C.			Concentrate				Tailings				Fe Recovery, %	Concentration Factor*
	Fe, %	CaO, %	Insol, %	Wt., %	Fe, %	CaO, %	Insol, %	Wt., %	Fe, %	CaO, %	Insol, %		
17	22·9	24·2	7·9	60·1	36·0	18·5	10·0	39·9	6·0	47·1	5·0	89·9	117
24	do.	do.	do.	55·7	36·4	18·1	9·6	44·3	5·5	47·9	4·2	89·4	120
27	23·0	24·2	8·5	57·7	38·2	17·4	9·7	42·3	5·4	49·1	4·1	90·0	119
32	24·6	17·8	15·3	72·6	37·8	13·8	16·8	27·4	8·8	30·4	11·0	91·8	115
35	22·0	24·6	9·6	61·3	35·9	17·0	11·0	38·7	5·8	47·6	6·8	90·9	118

* Concentration Factor $= \frac{\%\ \text{Fe in Concentrate (calcined)}}{\%\ \text{Fe in Ore (calcined)}} \times \%\ \text{Fe Recovery}$

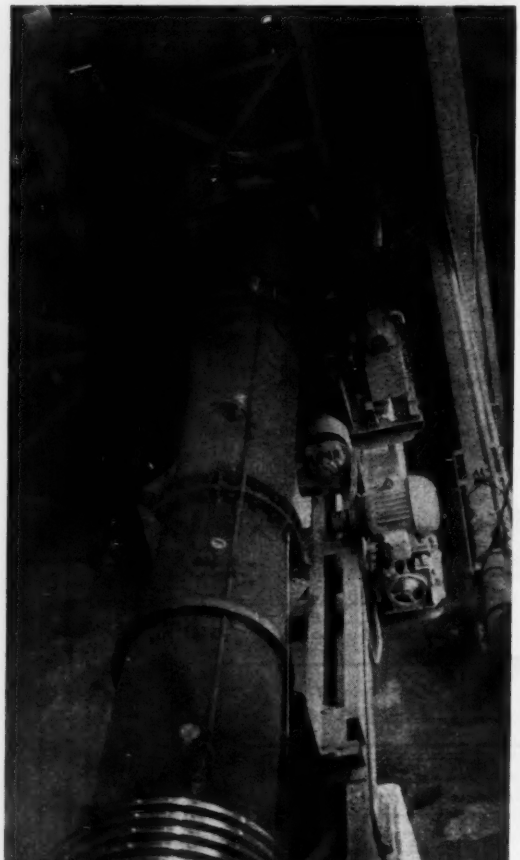

Fig. 5—Magnetic roasting kiln, looking towards feed end

determined with the kiln operating at temperatures of 700–790° C. measured at thermocouple No. 3.

Tests 17–27 were made on a bedded mixture of Frodingham ores, whilst tests 32 and 35 were carried out on the fines and coarse respectively of a Winns Wing No. 3 face ore, a slightly weathered Frodingham ore containing limonite and calcite, with subordinate amounts of siderite and chamosite. The high iron recoveries in all series should be noted, together with the high CaO content of the tailings.

It is now proposed to carry out a systematic examination by means of this equipment of all the ores representative of the Frodingham ore bed to determine the optimum conditions for the magnetic concentration of each type. This will be combined, as already indicated, with a full geological and petrographic study of the ores. A similar programme will then be extended to the Northants beds.

Other methods of concentration, apart from magnetic methods, are receiving consideration in the ore-concentration laboratory at Swinden House, and will be described in a later contribution to this Journal.[5]

Acknowledgments

So many people have been associated with this project that it is difficult to acknowledge them all by name. Special mention, however, should be made of Mr. F. W. Thrupp and Mr. S. V. Craddock for the laboratory work; Mr. W. O. Hedley for the design of the kiln and separator; and Mr. F. P. Reynolds for the operation of the equipment. The assistance of Dr. W. Davies of The United Steel Companies' Research and Development Department should also be acknowledged, particularly in connection with the petrological work, and that of Mr. R. J. M. Dixie of the Companies' Mines Department for the supply of ores.

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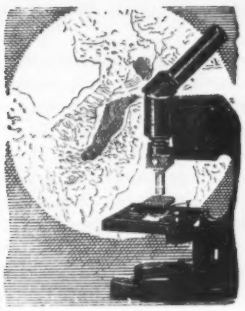

The Application of Oxygen Enrichment to Side-Blown-Converter Practice

By J. L. Harrison, F.I.M., W. C. Newell, Ph.D., D.I.C., A.R.C.S., F.R.I.C., and A. Hartley, B.Sc.

SYNOPSIS

The practical utility of oxygen-enriched air for side-blown-converter practice has been demonstrated in a series of works-scale experiments; the steel produced was of normal high quality and was used for commercial castings. The higher thermal efficiency arising from oxygen enrichment has been evaluated in terms of the various alternative factors such as shorter blowing time, higher steel temperature, and reduction in silicon and other fuel consumption. It has been shown that the increased flexibility of control of the side-blown-converter process has led to a more consistent composition of the steel produced, that a greater productive output from existing plant is possible, and that a higher proportion of scrap can be used in the charge. It is suggested that these factors may lead to an increased use of the side-blown-converter process not only in the foundry but also in larger basic furnaces for ingot-steel production.

Detailed observations made during these trials compare the temperature increments and changes in chemical composition during the blow, with normal practice, and it is shown that with regard to the total of oxygen passed into the converter the combustion process is more efficient with oxygen-enriched air. It is also shown that the wear upon the refractories of the converter lining is not increased by the oxygen enrichment.

HISTORICAL INTRODUCTION

THE idea of using oxygen enrichment can be traced back to the earliest days of pneumatic steelmaking, Sir Henry Bessemer having been aware of its potentialities when developing his Converter Process. Recent economic changes in the supply of raw materials, especially the potential cheapening of "tonnage" oxygen, have led to an awakening interest in the application of oxygen enrichment to steelmaking processes, not only to the pneumatic furnaces (blast-furnaces, cupolas, and converters) in which its main application would appear to be vested, but also to open-hearth and electric furnaces, either for the improvement of thermal efficiency or for the selective oxidation of carbon.

At the recent meeting of The Iron and Steel Institute, in Switzerland, Thring[1] and Durrer[2] discussed the potential application of oxygen to various metallurgical processes, and the reader is referred to these papers and the discussion which followed, for an appreciation of current views on the subject. More rapid melting of steel in the open-hearth furnace by the use of oxygen has been demonstrated by trials in both Canada[3] and the U.S.A.[4, 5, 6, 7] In Germany it had been shown in 1925, that oxygen enrichment applied to the basic Bessemer converter completely altered furnace conditions,[8] and that it was possible to make comparatively large steel-scrap additions to the metal during blowing.[9] Haag[9] also showed that with 35% of total oxygen in the blast the blowing time was halved without any increase in the blowing loss, and that the properties of the finished steel were normal. More recently Eilender and Roeser[10] have published a detailed account of the trials made at the Maxmillianshütte with total oxygen contents of the blast of up to 35%, and among the claims made are advantages in the recovery of manganese, the removal of sulphur, the control of temperature, and

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a lower nitrogen content. It is reported that the first Russian trials were made in 1934 by Mazgovoy, who introduced oxygen into a ladle, and it was stated subsequently[11] that Kapitza had reduced the blowing time for a bottom-blown Bessemer converter to only 1 min. by the use of oxygen, and that the finished steel had excellent properties. In 1946, Kondakov[12] published results of experiments using 50, 75, and 100% oxygen in the same type of furnace, and reported that not only was the nitrogen content of the steel low but the mechanical properties were improved, especially with 100% oxygen. It was also found by this investigator that whilst low-silicon pig iron could be satisfactorily blown with smaller blowing loss, the life of the refractory tuyeres never exceeded one heat. During the discussion at The Iron and Steel Institute Meeting already referred to, Robiette[13] mentioned some trials in a 2-ton side-blown converter using 90% oxygen, and he stated that a pig iron containing only carbon had been satisfactorily converted into steel. It appears, therefore, that prior to the present work little reliable information was available as to the effect of the use of oxygen-enriched air in the side-blown converter.

OBJECTIVE

The broad objective before the authors was the desire to attain more easily, by combustion, the high temperatures necessary for steelmaking. The fact that air consists of four-fifths of inert nitrogen by volume considerably lowers the maximum limit of temperature attainable by any atmospheric oxidation or combustion process, and whilst thermal recuperation or regeneration can be applied to certain large-scale processes to regain the sensible heat otherwise carried away with the nitrogen, this is not always possible. This broad objective can be evaluated as an enhanced degree of freedom in the steelmaking process, and it can be expressed in terms of the merits of higher liquid-steel temperatures (with all its concomitant merits, such as greater fluidity and increased length of fluid life for handling and refining), or in terms of the fuel economy for both carbon and silicon, not only in the converter itself but also in the preliminary iron-melting cupola, on account of the lower acceptable liquid-iron temperature. The objective can also be expressed in terms of economy in pig iron and its increased replacement by steel scrap, and not least by the saving of melting time and the potential increased furnace output and range of application of the converter process. The present investigation has verified and measured in a commercial steel foundry the practicability of this objective, and it has shown that in addition a closer control of composition is possible. This last point is of particular importance as it was anticipated that the shortening of the blowing operation might increase the problem of controlling the composition.

DESCRIPTION OF THE PLANT AND APPARATUS

The side-blown converters used for the investigations were originally operated as stock converters, and though they are now operated as normal converters the original oval shape and dimensions remain unchanged, as shown in Fig. 1. The siliceous monolithic lining is uniformly about 13 in. thick, and it is found that owing to the shortness of the body and nose of the converter the blowing loss, averaging 10%, is rather higher than for the more modern type of converter. There are six silica-brick 2-in. dia. tuyeres spaced 10 in. from the bottom of the vessel, which has a capacity of 40 cwt., increasing to 50 cwt. during the life of the lining which, during normal operation and without general patching, is about 60 heats. Very little wear occurs below the tuyere level, and the vessel bottoms, which are made of silica brick, remain in position for at least six times as long as the lining. Refractory wear tends to make the interior of the vessel spherical in form, but particular local wear occurs at the tuyeres, above the tuyeres, and at the body–nose junction.

Air is supplied to the converters at a pressure of 3 to 3½ lb./sq. in. by a positive-displacement Rootes blower, the volume blown being strictly proportional to the speed of rotation of the blower. The blast rate was normally 2700 to 3000 cu. ft./min., though by control of the speed of the blower, between 1600 and 4000 cu. ft./min. could be delivered.

Under normal operation, before these trials were commenced, the cupolas were charged with 20% of hematite iron and 80% of steel scrap with sufficient ferrosilicon added to produce a total silicon content in the molten iron of 1–1·2%. The temperature of

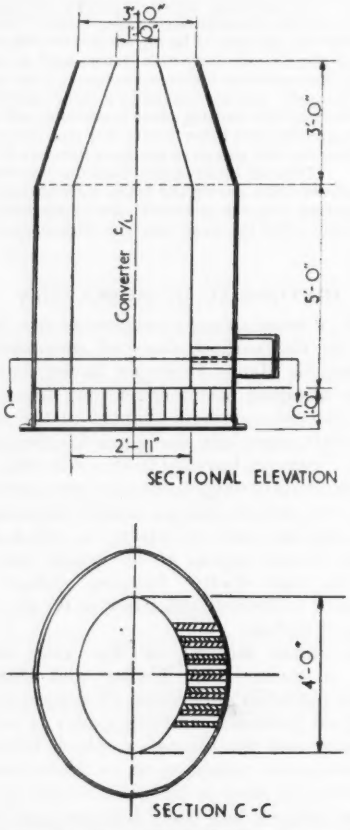

Fig. 1—Two-ton converter

the metal was between 1320 and 1340° C., and after blowing in the converter this was raised to between 1660 and 1680° C., or to between 1740 and 1750° C. by an addition of 0·4% of silicon (as 75% ferro-silicon) to the converter during the blowing operation. Owing to the larger temperature increment obtained with the oxygen-enrichment trials it was found unnecessary to add silicon with the cupola charge, and the silicon content of the molten iron for these trials was only between 0·5 and 0·7%. Desulphurization of the molten iron was carried out in a basic-lined ladle by means of 30 lb. of sodium carbonate per ton of iron. Owing to the poor quality of the coke and the steel scrap perforce in use, the sulphur content of the iron before treatment was between 0·12 and 0·15%, and occasionally values as high as 0·20% were obtained.

After the completion of the blowing operation the slag was removed, except during multiple heats. Deoxidation was effected by the addition of ferro-manganese and ferrosilicon to the bath as primary deoxidants, and of 2 lb. of calcium–silicon–manganese alloy, per ton of metal, in the ladle, as a final deoxidizer. The ladle used was of the stoppered-nozzle type, lined with fireclay bricks, and patching was performed, when required, with siliceous "compo."

The oxygen was obtained from an evaporator, which was already installed in the works for other purposes, of 14,000 cu. ft. capacity and 1500 lb./sq. in. working pressure. The authors are grateful to the British Oxygen Company, Ltd., for supervising the installation of the oxygen equipment, which included a series of low-pressure tanks of 14,000 cu. ft. total capacity at a pressure of 300 lb./sq. in. These were filled from the evaporator through a non-return valve, and from these tanks a constant flow of oxygen at a pressure of 20 lb./sq. in. was obtained by means of a pressure-reduction valve. The oxygen was then passed through a valve into the air main. The rate of flow was measured by a simple manometer connected across a calibrated standard orifice plate inserted in a section of the pipe which had been enlarged to a diameter of 4 in. over a straight length of 13 ft. especially for the purpose. The quantity of oxygen flowing was then calculated after making due allowance for the temperature and pressure correction factors. A check of the quantity of oxygen consumed was also obtained from the change in pressure within the tanks, and there was always good agreement between the consumption indicated by the two methods. It will be noted in the tables of results that the percentage of the total oxygen which was added as pure oxygen has been calculated.

Since the total amount of oxygen used in the operation appears to be fairly constant, from the point of view of cost the all-important factor is the fraction of the total oxygen which has to be added as pure oxygen and therefore paid for. As would be expected, this fraction is proportional to the oxygen enrichment, but it is also inversely proportional to the total percentage of oxygen in the blast. Thus, for a 5% enrichment 25% of the total of oxygen has to be added, for a 15% enrichment 50% has to be added, and for a 40% enrichment 85% has to be added. Thus, if oxygen enrichment of the order of 40% of oxygen is considered, the cost would be very little more if pure oxygen were used.

RESULTS

The authors' initial experimental scheme was to keep the works on a normal production basis as far as possible, and to inject additions of pure oxygen into the air blast so as to raise the total oxygen content of the blast by increments of 10%, *i.e.*, to 30%, 40%, etc. Table I shows the results obtained from the first few trials with 30 and 40% of total oxygen in the blast. These trials showed that the temperature was easily raised beyond the range of the immersion pyrometer employed (1750° C.), so that later an optical pyrometer was brought into operation. It was also evident that as the oxygen was additional to the normal air blast of 2700 cu.ft./min. the total blast volume had been increased, and that this factor might be influencing the increased blowing loss.

In the next series of trials, the results of which are shown in Table II, the total blast volume was maintained at 2700 cu. ft./min., and total oxygen contents of 30%, 40%, and 60% were compared with normal air-blown heats in which it is assumed that 20·5% of oxygen was present. With the higher percentages of oxygen the blowing

Table I

PRELIMINARY HEATS

Cast No.	Total Oxygen, %	Rate of Air Blast, cu. ft./min.	Rate of Oxygen Addition (from manometer), cu. ft./min.	Duration of Blow, min. sec.	Volume of Oxygen Addition (from gauge), cu. ft.	Volume of Oxygen from the Air Used, cu. ft.	Total Volume of Oxygen Used, cu. ft.	Total Oxygen Derived from Oxygen Addition, %	Weight of Cupola Metal Charged, cwt.	Blowing Loss, %	Temperature, °C	
											Cupola Iron	Final Bath
475	30	2700	400	11.0	4400	6000	10,400	42	42	4·6	1375	In excess of 1750° C.
476				9.0	4000	5000	9000	44	37	11·9	1355	,,
477				8.0	3500	4500	8000	44	39	11·4	1385	,,
480				9.0	3500	5000	8500	41	41½	5·7	1345	,,
481				9.30	3800	5200	9000	42	43	6·5	1345	,,
482				9.30	4000	5200	9200	43	42¼	6·5	1345	,,
487	40	2700	900	5.45	5000	3200	8200	61	38½	16·3	1400	,,
492				4.30	4000	2500	6500	61	38½	16·3	1360	,,

Table II

DETAILS OF HEATS BLOWN WITH OXYGEN-ENRICHED AIR AT A TOTAL RATE OF FLOW OF 2700 CU. FT./MIN.

Cast No.	Total Oxygen, %	Rate of Air Blast, cu. ft./min.	Rate of Oxygen Addition, cu. ft./min.	Duration of Blow, min. sec.	Volume of Oxygen Addition, cu. ft.	(Total Oxygen Used)/(Theoretical Oxygen)	Total Volume of Oxygen Used, cu. ft.	Total Oxygen Derived from Oxygen Addition, %	Cupola-Metal Composition			Blown-Metal Composition			Cupola-Metal Weight, cwt.	Blowing Loss, %	Temperature, °C.			Increment
									C, %	Si, %	Mn, %	C, %	Si, %	Mn, %			Cupola Metal (Immersion)	Final Bath		
																		Immersion	Optical	
520	20·5	2700	Nil	15	Nil	1·47	8100	Nil	3·22	0·62	0·62	0·07	0·10	0·07	43½	7·5	1320	1620		300
525				16		1·50	8600	"	3·06	0·62	0·62	0·13	0·09	0·06	43½	8·0	1320	1650		330
271				13		1·36	7100	"	3·07	0·64	0·47	0·09	0·09	0·02	43½	9·2	1290	1640		350
512				14		1·55	7500	"	3·06	0·59	0·53	0·16	0·07	0·04	45	9·2	1340	1620		280
739				17		1·43	9100	"	3·30	0·68	0·43	0·09	0·05	0·04	49	9·6	1360	1650		300
746				18		1·68	9700	"	2·91	0·78	0·57	0·09	0·01	0·06	49	8·5	1335	1660		325
980				18		1·61	9700	"	3·18	0·74	0·53	0·07	0·01	0·03	47	8·5	1320	1640		320
Average		..	..	16.10	"	1·51	8500	"	3·14	0·66	0·55	0·09	0·06	0·05	45½	8·5	1325	1640	..	315
530	30	2400	300	8.10	2700	1·39	6600	41	2·64	0·69	0·61	0·08	0·14	0·07	44	12·4	1340	..	1750	410
531				8.56	2800	1·38	7100	39	3·04	0·71	0·46	0·11	0·11	0·09	43	12·7	1385	..	1790	405
534				9.05	2800	..	7200	39	2·84	0·67	0·36	..	..	..	44	13·1	1395	..	1790	395
536				7.30	2400	1·26	6000	40	2·76	0·61	0·29	0·09	0·07	0·06	44	6·8	1355	..	1770	415
537				7.10	2300	1·18	5700	40	2·84	0·61	0·28	0·08	0·08	0·03	44	10·7	1380	..	1800	420
Average		..	..	8.10	2600	1·30	6500	40	2·82	0·66	0·40	0·09	0·10	0·07	44	11·1	1371	..	1780	409
541*	40	2000	700	6.43	4700	1·31	7400	64	3·07	0·80	0·36	0·08	0·13	0·08	45½	20·3	1350	..	1830	480
542				5.50	4300	1·30	6700	64	2·86	0·71	0·37	0·08	0·06	0·05	45	21·1	1370	..	1855	485
543				4.58	3600	1·12	5600	64	2·74	0·51	0·37	0·07	0·09	0·06	46	21·3	1360	..	1870	510
547				4.50	3800	1·18	5900	65	2·68	0·54	0·33	0·08	0·07	0·05	47	26·8	1360	..	1850	490
548				5.15	4000	1·19	6100	65	2·77	0·42	0·42	0·08	0·06	0·05	46½	21·0	1355	..	1820	465
Average		..	..	5.31	4100	1·23	6300	64	2·82	0·60	0·37	0·08	0·08	0·06	46	22·1	1359	..	1844	485
553†	60‡	1600	..	4.09	7000	..	8300	84	2·88	0·66	0·38	..	..	..	46	29·8	1370	..	1880	510

* The total blowing rate was 3100 and not 2700 cu. ft./min. for this cast
† Oxygen approximately 35% for first 30 sec.
‡ Oxygen manometer failed

losses were excessive, and it was realized that the blast rate would have to be reduced. However, these trials showed that for pig iron of the composition used, the oxygen enrichment reduced the blowing time to about one third of the normal time, and raised the temperature increment to 500° C. as compared with the normal 300° C. Moreover, no ferrosilicon had been added in the oxygen-enrichment trials. Figure 2 shows in graphical form the effect of the oxygen enrichment upon the blowing time, bath temperature, temperature increment, and blowing loss, for this uniform rate of flow of total blast of 2700 cu. ft./min.

The next series of trials was made with a total blast rate of 2000 cu. ft./min., but owing to the fact that the air blower was unable to deliver less than 1600 cu. ft. of air per minute the maximum concentration of oxygen which could be used was 35%. From the results of this series of trials, shown in Table III, it will be seen that the lower total blast rate has resulted in a blowing loss of about 10%, which is the normal loss without oxygen enrichment.

During the course of the trials using 30% of oxygen it was noticed that whilst at the commencement of the blowing operation a vigorous carbon flame was obtained from the mouth of the converter, this flame later decreased for a period and then increased again rapidly just before the culmination of what is generally recognized as the carbon elimination. It appeared that there was insufficient oxygen present or that the carbon combustion was being temporarily checked. For this reason it was decided to run a series of trials in which the oxygen concentration was raised from 30% to 35% at about midway during the operation, *i.e.*, after about 4 min. In this way the higher oxygen concentration was present when the bath appeared to be able to react with it readily, and the results (given in Table IV) show that the average blowing loss under these conditions was only 7·5%, which was an abnormally low figure.

The next series of trials was run under uniform conditions of a total blast rate of 2000 cu. ft./min. of 35% oxygen, but the blowing operation was interrupted before completion, at 2, 4, or 6 min. after the commencement, and blown-metal samples and temperatures were taken just as though the blow had been completed. After each heat had

been interrupted the blow was completed, but no further measurements were taken as it would not have been possible to have corrected for the unknown effect of the interruption itself upon the course of the heat. In this way a series of duplicated results for the condition of the bath at various stages of the blowing operation was obtained, and these results are shown in Table V and plotted in graphical form in Fig. 3. These results confirm the previous visually observed lull in the carbon combustion, so that there was apparently a period in the middle of the operation during which the temperature and the carbon content remained unchanged, but as this observation leads to such an irregularity in the curves these are dotted, and the individual results from the nine heats interrupted at 4 and 6 min. are plotted together with their average. Previous to this investigation a similar study of interrupted blowing operations, using air, had been completed on the same plant, and for purposes of comparison these results are reproduced graphically in Fig. 4. It will be seen that there is a slight tendency here also for a lull in the carbon reaction.

It was observed that with oxygen enrichment the end-point of the blow was sharper and easier to detect than with the normal air-blowing operation.

The last series of trials was made by using a total blowing rate of 2000 cu. ft./min. of 30% oxygen blown into a liquid-iron charge which had been melted in a cupola from steel scrap only. In this way the liquid iron after desulphurizing had an average temperature of only 1315° C. and an average silicon content of only 0·16%, and yet the blowing operation resulted in a temperature increment of 325° C., which enabled the metal to be cast satisfactorily. The results from these trials are shown in Table VI.

PROPERTIES OF THE FINISHED STEEL

After a careful examination of the chemical composition, physical condition, and mechanical properties, of typical specimens of the finished steel obtained from these trials, the authors are satisfied that the steel was in no way inferior to that normally produced. The average carbon content of the finished metal was the same as that normally obtained, but a most important point was that the carbon content of the steel from the oxygen-enriched trials was the more consistent. A statistical study was made of oxygen-enriched heats during the period of a month and compared with a similar number blown normally with air in the month immediately prior to the trials.

Table III

DETAILS OF HEATS BLOWN WITH OXYGEN-ENRICHED AIR AT A TOTAL RATE OF FLOW OF 2000 CU. FT./MIN.

Cast No.	Total Oxygen, %	Rate of Air Blast, cu. ft./min.	Rate of Oxygen Addition, cu. ft./min.	Duration of Blow, min. sec.	Volume of Oxygen Addition, cu. ft.	Total Volume of Oxygen Used, cu. ft.	Total Oxygen Derived from Oxygen Addition, %	(Total Oxygen Used)/(Theoretical Oxygen)	Composition of Cupola Iron			Composition of Blown Metal			Weight of Cupola Iron, cwt.	Blowing Loss, %	Temperature, °C.			
									C, %	Si, %	Mn, %	C, %	Si, %	Mn, %			Cupola Metal (Immersion)	Blown Metal (Immersion)	Blown Metal (Optical)	Increment
558				9.50	2700	6000	45	1·14	2·84	0·54	0·39	0·09	0·09	0·09	46	9·8	1345		1750	405
663				8.47	2400	5400	44	1·14	2·99	0·69	0·38	0·08	0·04	0·04	40	4·4	1350			400
665				7.45	2000	4800	42	0·94	3·34	0·54	0·39	0·08	0·13	0·03	40	11·8	1350	1730 (In excess of 1750)		400
671				9.23	2600	5800	45	1·02	3·33	0·79	0·47	0·08	0·05	0·04	42	10·7	1340			410
672				9.18	2600	5800	45	1·09	3·17	0·76	0·55	0·08	0·13	0·09	42	12·3	1330	"		420
723	30	1750	250	7.35	2000	4600	44	0·98	3·04	0·57	0·33	0·07	0·08	0·07	40	10·0	1330	"		420
733				7.43	2200	4900	45	1·02	3·28	0·49	0·39	0·08	0·09	0·10	38	9·2	1340	"		410
747				8.00	2200	5000	44	1·08	2·98	0·66	0·51	0·08	0·01	0·11	39	12·8	1370	"		380
748				7.24	2000	4600	44	0·99	2·94	0·75	0·48	0·12	0·08	0·12	40	10·0	1360	"		370
755				8.20	2300	5400	43	...	3·12	0·76	0·37	0·09	...	0·16	42	13·7	1350	"		400
907				9.15	2500	5800	43	...	...	...	...	...	0·12	...	44	9·5	1310	1735		425
964*				10.10	2700	6300	43	...	...	...	...	...	...	...	44	9·8	1295	1675		380
Average		..	..	8.38	2400	5300	45	1·08	3·10	0·65	0·40	0·08	0·08	0·08	41	10·2	1340	..	..	..
580†				9.20	3400	6300	54	...	2·94	0·69	0·36	...	...	...	42	...	1400	..	1820	420
589				7.56	2900	5400	53	1·16	2·82	0·61	0·39	0·08	0·14	0·08	42	9·5	1400	..	1810	410
595	35	1650	350	8.05	3000	5600	53	1·05	2·96	0·57	0·41	0·08	0·11	0·09	42	11·5	1365	..	1800	435
596				8.35	3200	5900	54	1·15	2·90	0·59	0·41	0·08	0·09	0·07	45	8·5	1380	..	1810	430
597‡				8.00	2800	5500	51	1·18	2·70	0·46	0·33	0·09	0·14	0·11	44	11·7	1370	..	1790	420
150*				7.05	2500	4900	51	...	2·69	0·72	0·39	...	...	...	40	10·0	1250	1750	..	500
Average		..	..	8.10	2900	5600	52	1·16	2·85	0·61	0·38	0·08	0·12	0·09	43	10·3	1361	..	1805	423

* Low cupola metal temperature
† Blowing loss not recorded, as some metal was left in converter
‡ First heat of the day

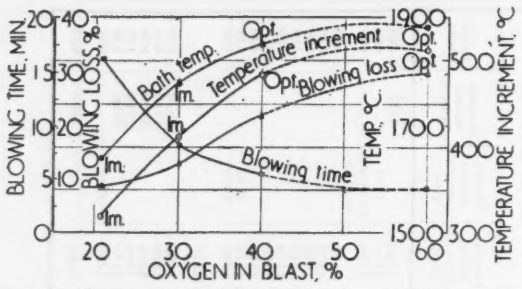

Fig. 2—Curve showing final bath temperature, temperature/increment, blowing time, and blowing loss, plotted against the oxygen concentration in the blast

and the results, for finished carbon and manganese contents, are as follows :

	Normal Air Blown (September, 1947)	30% Oxygen-Enriched Air (February, 1948)
Number of Casts ...	89	129
Average Carbon Content, %	0·24	0·25
Range of Carbon Contents, %	0·20–0·32	0·19–0·30
Readings Outside the Range 0·23–0·27% of Carbon, %	20·2	13·1
Standard Deviation of Carbon	0·0193	0·0178
Range of Manganese Contents, %	1·04–1·81	0·93–1·62
Readings Outside the Range 1·4–1·6% of Manganese, % ...	49·5	24·5
Standard Deviation of Manganese ...	0·1671	0·1420

The following determinations of the gas content of the finished steel were made by the vacuum-fusion method :

Cast No.	Oxygen in Blast, %	Temperature of Blown Metal, °C.	O_2, %	H_2, %	N_2, %
536	30	1770	0·005	0·00006	0·004
547	40	1850	0·005	0·00004	0·007

The oxygen contents are normal and the hydrogen contents are rather low. The nitrogen contents are normal, but in view of the high temperature of cast

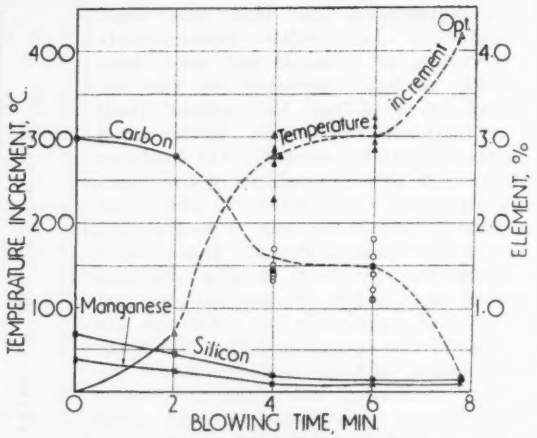

Fig. 3—Graph showing the chemical changes of the bath and temperature increment, using oxygen-enriched air containing 35% oxygen, in a side-blown converter

547 a somewhat higher nitrogen content might have been expected. If these results are typical, it would appear that the gas content of the steel produced is favourable and certainly lower than with bottom-blown operation.

Examination of polished sections prepared from the steels showed that the microstructures were normal. In the " as-cast " condition the structure consisted of coarse pearlite and ferrite. After the heat-treatment, in which the steel was soaked for 4 hr. at 950° C., followed by air cooling, the structure of pearlite and ferrite was also normal. The treatment, as usual, had a refining action on the grain-size, which was then about 6 (A.S.T.M.).

As stated previously in this paper, ferromanganese and ferrosilicon were added to the bath as primary deoxidizers and a final addition of calcium–silicon–manganese alloy was made in the ladle. This method of deoxidation produced comparatively small inclusions, nearly all of which were globular and distributed at random through the steel. They consisted almost entirely of complex non-glassy iron–manganese silicates and of iron–manganese sulphides. A few of the larger inclusions showed signs of a duplex structure

Table IV

DETAILS OF HEATS BLOWN WITH OXYGEN-ENRICHED AIR AT A TOTAL RATE OF FLOW OF 2000 CU. FT./MIN., BUT WITH OXYGEN RAISED FROM 30% TO 35% AFTER 4 MIN. BLOWING

Cast No.	Duration of Blow, min., sec.	Volume of Oxygen Added, cu. ft.	Total Volume of Oxygen Used, cu. ft.	Total Oxygen Derived from Oxygen Addition, %	(Total Oxygen Used)/(Theoretical Oxygen)	Composition of Cupola Metal			Composition of Blown Metal			Weight of Cupola Iron, cwt.	Blowing Loss, %	Temperature, °C.		
						C, %	Si, %	Mn, %	C, %	Si, %	Mn, %			Cupola Metal (Immersion)	Final Bath (Immersion)	Increment
563*	8.10	2600	5400	48	1·40	2·63	0·80	0·51	0·08	0·04	0·07	39	3·2	...	1750	...
564*	8.30	2800	5900	47	1·43	2·70	0·63	0·47	0·13	0·08	0·12	39	3·9	1390	1740	350
571	7.45	2500	5100	49	1·22	2·63	0·50	0·42	0·07	0·10	0·13	40	11·2	1335	1710	375
572	8.44	2700	5900	46	1·41	2·65	0·61	0·43	0·08	0·15	0·13	40	5·1	1345	1720	375
573†	11.10	3200	7100	45	...	...	...	...	...	...	...	40	8·1	1340	1740	400
574	7.43	2600	5800	45	1·28	2·84	0·71	0·39	0·10	0·17	0·08	40	13·7	1380	1730	350
Average	8.40	2730	5870	46·5	1·36	2·69	0·65	0·44	0·09	0·11	0·11	39¼	7·5	1360	1730	370

* The blowing-loss figures are obviously too low but indicate small loss
† First heat of day

but this was not the general case. The inclusion count showed that the total amount of inclusions was certainly no more than occurred in steel produced at this plant without the addition of oxygen to the blast.

Thus the microstructure and the quality of the non-metallic inclusions were almost exactly the same, and the quantity of inclusions was certainly no greater with the use of oxygen-enriched air than would be produced by the normal method of operation.

Tensile tests have been carried out on many of the casts of steel blown with oxygen-enriched air. The whole of the results are too numerous to detail here, but Table VII compares the tensile properties of the steel produced from a number of typical air-blown and oxygen-enriched heats.

EFFECT ON CONVERTER LINING

Most of the reports of work carried out on the application of oxygen enrichment to bottom-blown converters clearly indicate that one of the main problems affecting the success of the process is the very extensive wear encountered particularly in the region of the tuyeres. The work carried out in Russia by Kondakov[12] recorded a tuyere life of only one heat, and little success was achieved in finding suitably resistant refractories.

These experiments have now been going on for several months and there has been no decrease in the average life of the linings.

Although with oxygen enrichment the final temperature of the steel is higher than normal, the blowing time is shorter, so that the main bulk of the refractory probably does not reach a higher temperature. It is intended to insert thermocouples in the lining, to study the temperature gradients through the lining in the way indicated in the First Report of the Converter Refractories Sub-Committee.[14]

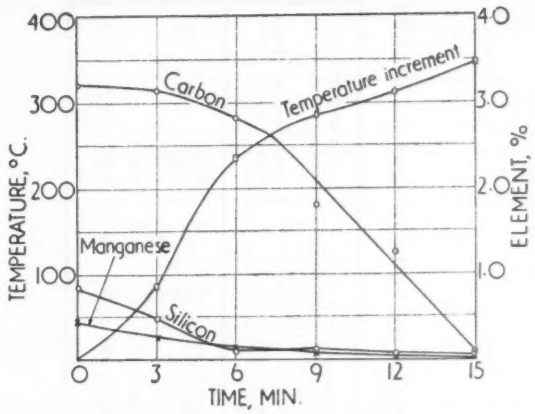

Fig. 4—Graph showing the chemical changes of the bath and temperature increment, during normal side-blowing operations

Additions of 40–50 lb. of sand were made between heats, and 30–40 lb. were added to the surface of the metal before blowing.

BLOWING LOSS AND THEORETICAL OXYGEN REQUIREMENTS

While the term " blowing loss " is quite familiar to operators of converter plants, some explanation of its meaning may be necessary for the benefit of those who are not intimately connected with such plants.

Table V

DETAILS OF HEATS WHICH WERE INTERRUPTED BEFORE THE BLOW WAS COMPLETED (2000 CU. FT./MIN. OF 35% OXYGEN-ENRICHED AIR)

Cast No.	Duration of Blow before Interruption, min. sec.	(Total Oxygen Used*)/(Theoretical Oxygen)	Cupola Metal Composition C, %	Si, %	Mn, %	Composition of Bath at Interruption C, %	Si, %	Mn, %	Weight of Cupola Metal, cwt.	Cupola-Metal Temperature (Immersion), °C.	Bath Temperature, °C. Optical	Immersion	Temperature Increment, °C.
602	2.00	3·30	3·05	0·76	0·41	2·89	0·53	0·31	44	1375	..	1435	60
603		2·83	2·98	0·69	0·36	2·82	0·36	0·21	44	1365	..	1440	75
604		2·73	2·80	0·56	0·32	2·62	0·25	0·18	44	1320	..	1370	50
614		1·50	3·14	0·98	0·38	2·60	0·65	0·27	38	1370	..	1485	105
617		3·05	2·86	0·60	0·36	2·68	0·27	0·18	38	1380	..	1490	110
Average	..	2·35	2·97	0·72	0·37	2·72	0·41	0·23	41¾	1363	..	1443	80
629	4.00	1·15	3·14	0·85	0·37	1·72	0·28	0·15	40	1335	..	1640	305
630		1·02	3·11	0·62	0·37	1·40	0·15	0·13	40	1350	..	1630	280
644		0·95	3·30	0·68	0·38	1·50	0·23	0·17	42	1360	..	1590	230
645		0·96	3·30	0·59	0·29	1·48	0·21	0·15	42	1340	..	1610	270
646		0·99	3·14	0·47	0·32	1·30	0·24	0·16	42	1340	..	1620	280
Average	..	1·01	3·20	0·66	0·35	1·48	0·20	0·15	41¼	1343	..	1623	280
978	6.00	1·43	3·22	0·50	0·33	1·59	0·15	0·11	46	1335	..	1650	315
980		1·14	3·30	0·61	0·38	1·25	0·18	0·21	46	1310	..	1620	310
39		1·77	3·15	0·72	0·56	1·84	0·16	0·22	42	1300	..	1590	290
40		1·77	2·82	0·72	0·62	1·48	0·24	0·20	42	1315	..	1600	285
Average	..	1·42	3·12	0·64	0·48	1·54	0·18	0·18	44	1315	..	1615	300
585	9.36	1·33	3·03	0·69	0·39	0·10	0·29	0·11	44	1395	1780	..	385
589	7.56	1·23	2·82	0·61	0·39	0·08	0·14	0·08	42	1400	1810	..	410
595	8.05	1·11	2·96	0·57	0·41	0·08	0·11	0·09	45	1365	1800	..	435
596	8.35	1·23	2·90	0·59	0·41	0·08	0·09	0·07	44	1380	1810	..	430
597	8.00	1·25	2·70	0·46	0·33	0·09	0·14	0·11	44	1370	1790	..	420
Average	8.26	1·23	3·00	0·64	0·38	0·08	0·15	0·09	44	1382	1798	..	416

* In this Table it has been assumed that no iron has been oxidized from the bath

Table VI

DETAILS OF HEATS BLOWN FROM ALL-STEEL SCRAP CHARGED TO THE CUPOLA; USING A RATE OF FLOW OF 2000 CU. FT./MIN OF 30% OXYGEN-ENRICHED AIR INTO THE SIDE-BLOWN CONVERTER

Cast No.	Duration of Blow, min. sec.	Volume of Oxygen Addition (from gauge), cu. ft.	Total Volume of Oxygen Used, cu. ft.	(Total Oxygen Used)/(Theoretical Oxygen)	Total Oxygen Derived from Oxygen Addition, %	Composition of Cupola Metal before Desulphurizing					Composition of Cupola Metal after Desulphurizing					Composition of Blown Metal					Weight of Cupola Iron, cwt.	Blowing Loss, %	Temperature °C		
						C, %	Si, %	Mn, %	S, %	P, %	C, %	Si, %	Mn, %	S, %	P, %	C, %	Si, %	Mn, %	S, %	P, %			Cupola Metal	Blown Metal	Increment
706	8.40	2300	5300	0·98	43	...	...	...	...	...	3·08	0·24	0·23	0·044	0·044	0·08	0·04	0·08	0·042	0·050	48	5·2	1310	...	...
790	8.12	2200	5100	1·07	43	...	...	...	...	...	2·78	0·23	0·22	0·057	0·039	0·10	0·05	0·10	0·055	0·049	46	14·7	1320	1630	310
928	7.20	2000	4500	...	44	2·66	0·30	0·44	0·132	0·037	2·97	0·10	0·20	0·051	0·013	...	...	...	...	...	48	...	1300	1640	340
968	9.45	2500	5900	...	43	2·99	0·16	0·27	0·106	0·037	2·97	0·10	0·28	0·054	0·027	...	...	...	...	...	48	7·8	1320	...	...
969	7.15	2000	4500	...	44	2·99	0·16	0·27	0·106	0·037	2·86	0·06	0·24	0·051	0·033	...	...	...	...	...	50	7·0	...	...	...
25	7.10	2000	4500	...	44	3·00	0·29	0·28	0·105	0·076	...	...	...	...	...	0·10	0·01	0·08	0·039	0·054	40	11·2	1325	...	...
Average	8.04	2200	5000	1·00	44	2·88	0·25	0·33	0·114	0·050	2·89	0·16	0·23	0·051	0·031	0·09	0·03	0·09	0·044	0·051	46	9·2	1315	1635	325

It will be appreciated from the text of the report, that although this figure varies under different operating conditions, the normal blowing loss, at the works in which the experiments were undertaken, is approximately 10%. This represents the average for side-blown-converter plants in this country, the range being between 8% and 14%.

Blowing loss results from chemical and mechanical causes. Chemical loss is due to the oxidation of the elements carbon, silicon, manganese, and iron. The oxidation of carbon, silicon, and manganese, is dependent on the original composition of the cupola metal, and accounts for the loss of between 4% and 5%. The oxidation of iron is governed partly by the composition of the cupola metal and also by the operating temperature and the length of the blow, and probably amounts to a further $1\frac{1}{2}$%, as estimated from the iron oxide normally found in the slag.

The mechanical loss is due to the ejection of reactive slag and metal during the blow, including also material carried away as fume, and accounts for the remainder of the blowing loss. This is controlled to some extent by the design of the converter and the volume and pressure of air employed, and any reduction of this loss would be an obvious improvement in the steelmaking process. The higher blowing losses with higher blowing rates are presumably accounted for by this mechanical loss. It was observed that the intensity of fume was greater with oxygen enrichment, and measures to decrease it are being considered. A fuller discussion on blowing loss appears in the First Report of the Side-Blown Converter Practice Sub-Committee.[15]

In order to estimate the efficiency with which the total oxygen entering the furnace has taken part in the chemical reactions, the theoretical oxygen required to oxidize the measured losses of carbon to carbon dioxide, silicon to silica, and manganese to manganous oxide, have been calculated from their stoichiometric equivalents, in terms of cubic feet of oxygen. It has then been assumed that 1·5% of iron has been oxidized and is retained in the slag as ferrous oxide, and the equivalent of this has been added to give a figure for the total theoretical oxygen required. In the tables of results this figure has been divided into the actual oxygen consumption to give a measure of inefficiency or excess oxygen consumption. It will be seen that 50% or more excess oxygen may normally be used, but that the excess required is markedly reduced by oxygen enrichment. Thus, as might be expected, reduction in the nitrogen content of the blast leads to a more efficient utilization of the total oxygen blown into the furnace, or to a better "oxygen balance." For the interrupted heats, since oxidation of the carbon and silicon was incomplete and the iron oxide content of the slag very small, it is assumed that the iron loss by oxidation was negligible.

DISCUSSION OF RESULTS

From experience gained during several months' continuous operation with oxygen-enriched heats the authors are satisfied that even a moderate degree of oxygen enrichment applied with little or no modification to existing converter units can lead to an improvement in steelmaking practice. The fact that

Table VII

MECHANICAL PROPERTIES OF STEEL (IN THE FULLY HEAT-TREATED CONDITION)

Cast No.	Total Oxygen, %	Composition of Steel					Tensile Properties		
		C, %	Si, %	Mn, %	S, %	P, %	Ultimate Tensile Strength, tons/sq. in.	Elongation on 2 in., %	Reduction of Area, %
110	20·5	0·26	0·32	1·50	0·059	0·039	39·6	24·0	36·4
167	20·5	0·26	0·37	1·66	0·039	0·033	39·2	25·0	37·8
329	20·5	0·27	0·34	1·44	0·021	0·060	38·9	32·0	44·6
479	20·5	0·22	0·42	1·40	0·067	0·060	37·0	26·5	44·6
680	20·5	0·24	0·35	1·48	0·059	0·053	38·1	24·0	39·2
704	20·5	0·23	0·31	1·36	0·045	0·058	36·1	23·0	39·2
726	20·5	0·25	0·24	1·44	0·066	0·054	39·0	23·0	30·6
839	20·5	0·25	0·34	1·33	0·032	0·046	35·4	27·0	44·6
Average	..	..	..	..	..	..	37·9	25·6	39·6
21	30	0·24	0·43	1·40	0·033	0·040	40·0	30·0	49·8
428	30	0·25	0·44	1·50	0·034	0·050	38·0	32·0	53·4
472	30	0·28	0·41	1·30	0·038	0·067	34·8	32·5	54·6
482	30	0·24	0·39	1·44	0·025	0·060	38·4	31·5	49·8
591	30	0·26	0·34	1·40	0·044	0·066	37·8	30·0	45·9
784	30	0·23	0·45	1·44	0·059	0·060	40·8	32·0	54·6
788	30	0·23	0·45	1·42	0·060	0·061	38·2	27·0	51·0
964	30	0·26	0·40	1·50	0·059	0·051	36·5	28·0	51·0
Average	..	..	..	..	..	..	38·1	30·0	51·2

a closer degree of control can be gained in this steel-making operation is a feature of value, which should favourably influence the future application of the side-blown converter. The authors would not put undue significance upon the shortening of the blowing operation for the average foundry, where melting capacity is generally adequate, but they would suggest that larger furnaces of this type might, with oxygen enrichment, be employed for bulk ingot-steel production, especially in basic-lined vessels. At the same time the significance of higher steel temperatures to a foundry requiring only small quantities of steel intermittently is obviously an attractive feature, especially where thin-section castings are being made and greater fluidity is desired.

The fact that under normal operating conditions with air blowing, such a large excess of air being passed through a side-blown converter has not been reported before, as far as the authors are aware, and the fact that oxygen enrichment so markedly increases the efficiency of the oxygen reactions is an additional factor of merit. This is in accord with the higher oxygen efficiency reported by Kondakov[12] for bottom-blown converters. The apparent reason for this is that normally the high blowing rate, necessary for reasonably rapid completion of the heat, is too high for complete chemical reaction with the bath. This point is intimately linked up with the blowing loss; normally the blowing loss is the dominating factor limiting output, but by reducing the rate of blast flow through the converter the blowing loss can be substantially reduced, as shown by these trials. Clearly, therefore, blowing loss is not so much dependent upon rate of oxidation as upon rate of efflux of gas from the converter, though in this connection it should be pointed out that carbon monoxide (or dioxide) has also, of necessity, to pass out as a gas from the vessel, and with the trials made in which the oxygen content was varied to stabilize the rate of the carbon reaction the blowing loss was abnormally low.

In normal side-blown-converter practice it is found that the carbon oxidation only proceeds with rapidity when the bath has reached a temperature of over 1400° C., and it is a generally accepted idea that the main function of the silicon is to raise the temperature of the bath, by oxidation, to this requisite temperature. This phenomenon is well shown in Fig. 4. However, with oxygen enrichment and in the absence of silicon the carbon combustion proceeds quite rapidly even at low temperatures. The probable explanation of this is that the oxygen enrichment has so accelerated the carbon combustion that it is sufficiently high even at the low temperatures. Theoretically it should proceed throughout the possible temperature range, but elevation in temperature should accelerate the combustion.

After the carbon combustion has proceeded about half-way and with a temperature increment of 200–300° C., the carbon reaction and temperature tend to become stationary for a period. This is a remarkable fact, which it is not easy to explain (*see* Fig. 3). As has been pointed out, the same effect can be seen from the normal air-blown heats to a slight extent (*see* Fig. 4), though it must be admitted that no significance had previously been attached to this. One explanation of this phenomenon is that at this stage the slag passes through a viscous and sluggish condition so that oxidation is hindered. The great variation in the oxygen efficiencies at the different stages of the blow (*see* Table V) lends support to this idea, as does also the fact that raising the oxygen content at the sluggish period (*see* Table IV) results in a poor oxygen efficiency.

Probably by reason of the high temperature attained by these trials the silicon is not so completely oxidized, or, alternatively, there is some reversion of silicon back to the bath from the silica of the slag. The average effect would appear to be an increment of 0·05% of silicon, which means some economy in the quantity of deoxidants to be added.

A consideration of the economic aspects of oxygen enrichment is a rather complex matter. The cost of adding 1000–2000 cu. ft. of oxygen per ton of steel must be set against a series of factors, such as enhanced fluidity and higher output or shorter working day, which will vary in value with different works. But apart from these factors, economies in materials, including cupola fuel, pig iron, ferrosilicon, and blowing loss, are commensurate with the probable ultimate cost of oxygen of suitable or "tonnage" quality, as it is known.

As yet the side-blown-converter process is used predominantly for making carbon steel and manganese steel (the manganese being added in molten form), but the higher temperatures obtainable with oxygen enrichment open up the possibility of making substantial cold additions to the blown carbon-steel base, so that it should be practicable to make higher alloy steels by this process. Trials are shortly to be made upon this proposal.

CONCLUSIONS

It is concluded that oxygen enrichment of the side-blown-converter blast is likely to be widely applied in the future on account of the following technical advantages which have been demonstrated in this report:

1. Higher steel temperature is possible, with its attendant advantages in the foundry of increased fluidity and reduced skulling loss.
2. A shorter blowing cycle is possible, thus permitting a higher steel output from a given plant or, alternatively, a smaller plant for a given output.
3. Lower molten-iron temperature can be accepted thus permitting some fuel economy in the cupola.
4. A higher scrap charge may be used in the cupola, thus permitting a reduced pig-iron consumption.
5. Reduction in the need for ferrosilicon addition during cupola melting or during the blowing operation.
6. Reduction in the blowing loss.
7. Easier control of the end-point and a proven more consistent final composition.

From experience gained during several months of continuous operation the authors are of the opinion that the side-blown converter with oxygen enrichment is likely to be increasingly used, not only in foundries for carbon and manganese steels but also for bulk ingot-steel production.

This last suggestion would probably necessitate modifications in design in the light of the altered aerodynamic conditions inside the converter, as well as the use of basic lining in larger units.

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Elimination of Sulphur in the Blast-Furnace

By D. Joyce

In spite of the general trend today as compared with pre-war years of increased sulphur in the coke used, and on many occasions in the ores available, the blast-furnace is still expected to produce iron with sulphur content low enough not to hamper steel production even on the higher hot-metal charges that may have to be used in the steel furnaces to compensate for scrap shortage. It is definitely true that the sulphur content of the iron produced on any furnace is a good guide to furnace condition, or, inversely, to meet a required sulphur grade furnace conditions must be right. All are aware that very small deviations from desired furnace conditions quickly reflect themselves in off-grade sulphur casts.

Since, generally speaking, above 90% of the sulphur charged in the blast-furnace comes from the coke, it is at once obvious that the more economically the furnace can be worked as regards coke rate the less sulphur load the furnace has to carry, and this is an important function in the final slag formation on which any particular furnace can be operated. In the attainment of such operation coke quality, both chemically and physically, plays a predominant part; physically because the coke should be strong enough to withstand abrasion and solution loss by the ascending gases and should provide sufficient porosity in the stock column for rapid and smooth driving, and chemically because—apart from low ash and, of course, high carbon—a coke of as low a sulphur content as possible is required. The lower the sulphur in the coke charged, the more economical furnace operation becomes, in that lower-sulphur coke permits the use of leaner slags, less limestone additions, more room for ferrous materials, increased production and lower coke rates. Thus, given low-sulphur coke and lower coke rates, less sulphur has to be dealt with, and furnace production and economics are greatly benefited.

It is obvious, therefore, that the best way to eliminate sulphur in the blast-furnace is to charge as little as possible, and the sulphur in the coke is thus of prime importance in furnace operation. It was for this reason that the coke specification for blast-furnace use put forward at a recent Blast-Furnace Conference listed sulphur content at 1·0% maximum wherever possible. Since, however, it may be some time before this specification can be met in some localities, and since there is still the tendency for the available ores in many districts to increase in sulphur content, furnace operation will have to be so adjusted to produce the maximum economical tonnage per furnace without deterioration in iron quality.

SULPHUR PICK-UP

Apart from the large proportion of the sulphur present that is usually found in the fuel, sulphur can also enter the furnace either as sulphate or sulphide in each member of the charge. Recent tests on American furnaces[1] demonstrate that, taking 0·05% as the maximum limit of sulphur in the iron, at planes 19 ft., 2 ft., and 1 ft. above the tuyeres the metal contained 1·4, 3·6, and 1·4 times, respectively, the maximum limit. At 19 ft. above the tuyeres the metal had taken up 3·33% of the sulphur charged into the furnace, whilst at 2 ft. above the tuyeres the metal had taken up 12% of the available sulphur. These results demonstrate the affinity the metal has for sulphur in the upper part of the furnace, whilst in the bosh the metal readily continues to take up further sulphur. This may be due to the fact that some part of the metal drops are not coated by slag and are thus subject to contamination with the sulphur liberated by combustion of the coke at the tuyeres. At the same time analyses of limestone samples taken from a plane 19 ft. above the tuyeres showed that the lime had taken up 0·77% of sulphur, which was approximately 26% of the available sulphur originally charged, this in addition to the 3·33% of the available sulphur taken up by the metal at this plane. Hence the higher the coke sulphur, the heavier the contamination liable to take place. Determinations of the forms of sulphur in coke samples at the 19-ft. plane showed that approximately 25% of the sulphur in the coke had been removed by the time it reached this point and that the sulphur removed was that which existed in the coke as ferrous sulphide and free sulphur.

Further proof of this accepted fact that desulphurization takes place below the tuyeres in the hearth, both as the drops of iron trickle through the slag layer and also on the interface connection between the slag and iron layers, was shown at Consett some months ago when, before casting No. 2 furnace, a local slip in front of one of the tuyeres forced iron and a semi-fused mixture into the tuyere blowpipe. The analysis of this iron from the blowpipe showed 0·400% of sulphur, and yet the following cast, some 15 min. later, contained 0·085% of sulphur and the next cast 0·075% of sulphur.

SULPHUR ELIMINATION

The foregoing is a brief description of how the sulphur enters the iron in its passage through the bosh and tuyere plane into the hearth. To eliminate this sulphur from the iron as cast from the furnace, the

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operator has one main source of control, namely by the slag produced. This includes slag formation, slag temperature and fluidity, and slag volume. Firstly it is possible to control sulphur content in the iron produced to the tolerant limit by high-lime slags with relatively low slag volumes. This increases the melting point of the slag which, together with the tendency for a greater temperature head at the tuyeres and higher hearth temperatures, increases the slag's attraction for sulphur and promotes the production of lower-sulphur irons. This method of slag control for low-sulphur-iron production, however, is beset with difficulties, for in carrying high-lime slags to effect sulphur removal there is always the danger that the furnace might be operating on a slag the formation temperature of which is above the critical temperature developed. If this occurs and the critical temperature developed is not sufficiently high to bring all the lime into solution, only one factor can occur, namely that excess lime must be deposited in the hearth, and this can lead only to furnace derangement unless immediate steps are taken to rectify matters. On the other hand too lean a slag tends to extend the zone of fusion and does not allow sufficient heat concentration, and is not capable of either imparting heat to the iron drops in their passage to the hearth or of desulphurization. Consequently such slags result in low-temperature high-sulphur iron. Under these conditions heat concentration cannot often be restored, even by extra coke, until the slag formation temperature has been increased by alteration to the slag composition. It is therefore essential to strike a medium, since slags of high basicity are against economic furnace operation and too lean slags give off-grade sulphur iron. In this respect slag volume plays an important part. It is realized, of course, that some furnaces are operating on a self-fluxing burden where slag volumes are high due to the ores available, but this paper is chiefly concerned with furnaces operating on foreign ores and a small proportion of home ores, as at Consett. The sulphur contents of the majority of the ores at present used at Consett range from 0·014 to 0·060%; five ores of higher sulphur content are, however, in use, and these are as follows:

Ore	Type of Ore	Sulphur, %
A	Refractory	0·18
B	Spathic	0·62
C	Spathic	0·45
D	Calcined	0·85
E	Soft	0·60

CONSETT PRACTICE AND GENERAL CONSIDERATIONS

For maximum efficient furnace operation at Consett, a slag volume of about 900–1000 lb. per ton of iron produced has been found to be ideal. Slag volumes around this figure have given regular furnace operation, whilst slag volumes much below 850 lb. have tended to establish irregularities and at the same time—when carrying the higher-sulphur ores in the burden—have called for increased slag basicity, with less efficient furnace operation. On 900–1000-lb. slag volumes no difficulty has been experienced with up to 20% of the higher-sulphur ores on the burden, nor has the need been found to run slags of higher basicity to assist sulphur removal. This factor can be simply explained; at Consett the sulphur content of the slag when operating on low-sulphur ores has been found to be as low as 1·4–1·5%, or, on occasions, even lower, and thus on operating with some ores of higher sulphur in the charge the same slag formation with regard to lime and silica and volume has been able to deal with the higher sulphur charged without being sulphur-saturated. The slags at Consett on the production of basic iron average from 1/1 to 1/1·10 straight silica-to-lime ratio.

Once, therefore, the slag composition and volume have been established to meet the desired requirements for sulphur in the iron produced, the main factors for sulphur elimination in the blast-furnace are maintenance of hearth temperature and slag fluidity. It might be argued that by increasing slag volume above the maximum for sulphur removal there is a tendency to increase coke consumption, since each increase in the slag produced demands extra coke, yet in practice this has not proved so, since the lower slag volume that might be run with its necessary increased basicity demands just as much coke, owing to the increased slag formation temperature, without the additional advantages of smooth furnace operation. To revert back, however, to hearth temperature and slag fluidity; there is no doubt that slag temperatures obtained on flushing are a means of forecasting the sulphur and silicon of the ensuing cast. It is quite possible that more use will be made eventually in blast-furnace operation of actual slag temperatures, since by this means changes to meet new conditions in furnace operations could be made earlier. There is obviously on certain slag compositions a small critical range above which slags of the necessary quality are maintained, but below which deterioration in slag quality quickly takes place if not corrected in time. This has, on occasions, been proved so at Consett, primarily due to the fact that on foreign-ore practice with ores of variable quality being used, burden changes are frequent, and stabilization of burdens to maintain slags of desired mineralogical composition for maximum furnace economy cannot always be accomplished. It is not surprising, therefore, that on some slags small changes in furnace operation can readily bring about major changes in the melting points, viscosities, and mineralogical compositions of the slags. This is more especially the case with regard to mineralogical composition when the formations of slags as produced are near the phase boundary lines, and small chemical changes are capable of bringing about physical changes, each physical change requiring different formation temperatures. This inability to stabilize burdens for any length of time on foreign-ore practice prevents full-scale slag tests being run and tends to retard maximum furnace efficiency.

The melting points of the usual slag-forming constituents are as follows:

	°C.
Silica	1710
Alumina	2050
Lime	2500
Magnesia	2100

Since the alumina content of the slags on the Consett furnaces varies between 14 and 22%, and since alumina has an important function in any slag mineralogical composition, the changes that can take place in slag composition can readily be understood. These changes play an important part in the desulphurizing power of the slags produced.

With regard to slag fluidity, which plays an important part in sulphur removal, much discussion has taken place in the past concerning the effect of magnesia. At Consett the magnesia content of the slags ranges from 3 to 7%. This is not done to increase slag stability in order to extend the uses of cold blast-furnace slag, but simply because dolomite is used to augment the limestone supplies available. The respective analyses of the dolomite and the limestone are as follows :

	Dolomite	Limestone
SiO_2, %	0·40–1·00	1·0–4·00
$MgCO_3$, % ...	38·00	...
$CaCO_3$, % ...	58·00	92–97
Sulphur, % ...	0·025	0·05–06
Phosphorus, %...	0·005	0·007
H_2O, % ...	1·00–2·00	...

Within the narrow range of magnesia fluctuation at Consett, little change has been found in the slags as flushed from the furnaces, although magnesia no doubt does increase slag fluidity. On occasions, on all limestone, very little change has been found in the desulphurizing power of the slags produced. Holbrook and Joseph,[2] however, have shown that magnesia is not as active for sulphur removal as lime, and Dale[3] reports the switching of one furnace from 100% dolomitic limestone to calcite owing to the continued production of high-sulphur iron. On this furnace, although there was 15% more dolomitic limestone used, by weight, than the calcium carbonate that replaced it, the desulphurization by the limestone was perfectly satisfactory. On this question of magnesia, however, it is of interest to quote what can be done with high-magnesia slags, as shown by Nickel[4] at the Wisconsin Steel Works. The problem that confronted the operators on this plant was the production of low-manganese iron from ores which were of low alumina content. It was found that slag of suitable mineralogical composition for furnace operation and sulphur removal could be produced with low-alumina slags, provided that the magnesia content of the slag was maintained around 20%. This was more than ever necessary, since to maintain sufficient sulphur removal on low-alumina slags the amount of bases present must be increased. As high-lime slags are a source of trouble for furnace operation, the use of high-magnesia slags was preferable. The success of the high-magnesia slags in effecting the desired sulphur removal is shown in Table I, the data for which are taken from Nickel's paper.

In determining the desired slag quality for proper desulphurization it has to be realized that two types of slag are produced in the furnace. Firstly, the slag formed above the tuyeres, which is naturally more basic, and, secondly, the final slag formed after fusion with the coke ash below the tuyeres. The slag composition above the tuyeres plays an important rôle in furnace driving and coke rate, and it should be of low viscosity and melting point to attain this object. The final slag should be of such formation to develop the maximum temperature head at the tuyeres and of such fluidity to effect maximum desulphurization. It is obvious, therefore, that the best slag formation for free furnace movement above the tuyeres may not be suitable for the desired composition of the final slag to effect proper sulphur removal. A medium may therefore have to be struck, but when the variation between the two slag compositions is so wide that compromise is almost impossible it has been found advantageous to produce slags of the lowest viscosity and melting point and to effect sulphur removal by treatment during the casting process. Once, however, slag formations for optimum furnace operation on the required sulphur iron grade have been found, it is then a question of maintaining furnace condition as established. This at times is far from easy, as variations in analyses of the ores and/or coke charged,

Table I

OPERATING DATA DURING USE OF HIGH-MAGNESIA SLAGS AT WISCONSIN (NICKEL)

Test No.	Iron Specifications				Time on Furnace, Days	Iron in Specifications, %	Production, tons/day	Coke, lb./ton pig	Flue Dust, lb./ton pig	Slag Volume lb./ton pig
	Silicon, %	Sulphur, %	Phosphorus, %	Manganese, %						
1	2·50–3·25	0·050 max.	0·101–0·200	1·00–1·20	5	90	541	1890	117	855
2	3·50–4·00	0·050 max.	0·101–0·200	1·00–1·20	3	64	533	1905	122	860
3	1·50–2·25	0·050 max.	0·101–0·150	0·80–1·00	12	77	620	1732	120	968
4	1·00–1·50	0·040 max.	0·101–0·150	0·41–0·60	13	89	583	1740	94	1115

	Slag Analyses			
	Magnesia, %	Silica, %	Alumina, %	Lime, %
1	18·80	37·02	17·30	28·80
2	18·36	37·41	14·20	27·60
3	20·79	35·60	10·80	31·70
4	22·30	36·06	6·80	33·80

Table II
DATA FOR TYPICAL CONSETT SLAGS

	Basic				Hematite	
	1	2	3	4	1	2
Silica, %	34·90	34·40	35·40	33·50	29·2	30·5
Alumina, %	18·24	16·94	16·96	15·84	19·73	20·25
Ferrous oxide, %	0·45	0·64	0·45	0·66	0·71	0·20
Manganese oxide, %	0·98	1·81	1·72	2·27	0·63	0·40
Calcium oxide, %	34·00	35·07	33·91	37·62	39·66	36·40
Calcium sulphide, %	3·98	3·89	3·85	2·93	5·20	5·92
Magnesia, %	6·53	6·33	6·62	6·43	4·46	6·08
Alkalies, %	0·85	0·64	0·64	0·64	...	...
Total sulphur, %	1·77	1·73	1·71	1·30	2·31	2·62
Slag volume, lb./ton pig	840	900	930	980	700	1000*
Iron Produced :						
Silicon, %	0·90	0·70	0·70	0·52	1·75	3·50
Sulphur, %	0·100	0·095	0·084	0·072	0·036	0·025
Phosphorus, %	0·56	0·340	0·400	0·520	0·060	0·070
Manganese, %	0·54	0·95	0·94	1·25	1·30	1·25

* With 33% of high-sulphur ores on burden.

even though apparently only small, can soon bring about a change in slag conditions. Where large fluctuations in ore analyses and in coke ash and sulphur contents are to be expected, furnace operation can never be maintained at its maximum, since furnace conditions must be maintained on the hot side to act as a buffer to take care of these fluctuations in the composition of the materials charged, which can quickly throw furnace conditions out of balance. There can be no doubt that some slags, owing to their mineralogical composition, are bound to be more sensitive to slight chemical changes that may occur, and that when operating on such slags difficulty may be experienced in maintaining the desired sulphur content in the iron. There can also be no doubt that changes in the mineralogical state of the slag under such conditions can bring about decided improvements. The advantages of operating furnaces on a more or less stabilized burden cannot be overlooked, in that slags of desired composition can be maintained. Typical blast-furnace slags at Consett are listed in Table II, together with the corresponding slag volumes and iron analyses.

As previously stated, it is a well-accepted fact that the slag layer in the furnace is a powerful desulphurizer, not only as the iron drops percolate through into the hearth, but also on the interface connection between the slag and iron layers. The advantages, therefore, of periodic flushing as against endeavoured continual flushing can readily be seen. Further advantage of this slag layer was taken some years ago in America, as reported by Steudel.[5] The slag formations on two furnaces were altered to produce slags of such mineralogical composition as would promote more efficient furnace operation, and at the same time the slag volumes on the furnaces were reduced to figures previously deemed subnormal. The results achieved are shown in Table III.

In addition, to promote sulphur removal with the lower slag volumes, only one flush was made before cast, and care was taken not to blow the furnace at cast time, leaving as much slag in the furnace as practicable. Thus the average time of slag in the hearth was lengthened, the opportunity for slag–metal contact was increased, and maximum sulphur removal was approached. By this method it was stated that sulphur absorption in the slag was increased approximately 20% by retention of more slag in the furnace, particularly at cast time. At Consett three flushes are generally run between casts, working front and back notches alternately. Under normal operation the notches are not allowed to blow to any extent, primarily because once blowing at the notches commences, difficulty may be experienced in botting. At the same time, blowing hard at the tapping-hole towards the end of casting is not practised. Thus by working in flushes and retaining some slag in the furnace at cast, there is a tendency to aid sulphur removal. Care must be exercised, of

Table III
SLAG VOLUMES AND COKE CONSUMPTIONS IN NORMAL AND TEST PRACTICES (STEUDEL)

	Normal Practice	Test Practice	Difference
Bessemer Practice :			
Slag volume, lb./ton pig	959	752	−207
Coke consumption, lb./ton pig	1898	1783	−115
Scrap, lb./ton pig	18	45	+27
Sinter in burden, %	Nil	Nil	...
Basic Practice :			
Slag volume, lb./ton pig	1053	782	−271
Coke consumption, lb./ton pig	1841	1701	−140
Scrap, lb./ton pig	62	100	+38
Sinter in burden, %	12·6	Nil	−12·6

course, not to allow slag to show at the tuyeres and thus retard combustion of the coke.

DISCUSSION

What of the future? Much interest is again apparent in the oxygen enrichment of blast to the furnaces as a means of obtaining higher productions at lower coke rates, or to be used intermittently as required to provide more positive control of hearth conditions in a furnace in the shortest possible time and thus obtain further control of sulphur elimination. This opens up a wide field of possibilities, but much has to be done, both in research under actual furnace operating conditions and as regards the price of oxygen, before oxygen enrichment can be truly applied. A further proposal of injecting flux into the furnace through the tuyeres as another means of quick and immediate slag control to effect maximum sulphur removal has been put forward. This would allow the carrying of low-melting-point bosh slags for maximum furnace driving rate and would reduce the amount of limestone charged into the furnace, which would tend to make available in the stack more heat and gases of greater reducing power. The method of injection, the need of increased hearth temperature during the injection period, and tuyere conditions during injection, are the problems of this proposal.

There are two points regarding sulphur elimination which have not been mentioned; both are well known. The first is the effect of manganese on desulphurization in the blast-furnace. If manganese is available in the iron in a furnace hearth, it reacts with iron sulphide to form manganese sulphide, which, being of lesser density, comes into contact with the slag on the interface connection between the slag and iron layers and is changed into calcium sulphide, which passes into the slag. The effect of manganese therefore is a definite aid to sulphur removal, both in the furnace and also in the hot-metal ladles. At Consett the furnaces have always been found to be more capable of maintaining low-sulphur grades when operating on $1\frac{1}{4}$–$1\frac{1}{2}$% of manganese in the iron as against the lower manganese ranges of 0·6–0·8% with the same slag formation and temperature. With hot-metal handling as at Consett, where the furnace casting ladles are handled by a 90-ton overhead crane and teemed into smaller ladles for transit to the steelworks, appreciable decreases in sulphur content have been noted between the hot metal in the furnace casting ladles and that received by the steelworks. This effect of manganese on sulphur removal in hot-metal ladles has been admirably shown by Wheaton,[6] whose data are reproduced in Table IV.

Table IV

EFFECT OF MANGANESE ON SULPHUR REMOVAL IN THE HOT-METAL LADLE (WHEATON)

Manganese at Blast-Furnace, %	Sulphur at Blast-Furnace, %	Sulphur at Open-Hearth Mixer, %
1·44	0·105	0·049
1·38	0·096	0·035
1·35	0·066	0·039
1·17	0·068	0·032
1·26	0·099	0·044
1·35	0·110	0·030
1·44	0·098	0·029
1·47	0·093	0·039
1·38	0·071	0·042
1·47	0·059	0·043

Table V

SULPHUR VARIATIONS WITH DIFFERENT SIZE GRADINGS

	Soluble Sulphur, %	Insoluble Sulphur, %	Total Sulphur, %
Ore *A*:			
Lumps	0·44	...	0·44
Rubble	0·55	...	0·55
Smalls	0·62	...	0·62
Ore *B*:			
Lumps	0·64	...	0·64
Rubble	0·45	...	0·45
Smalls	1·08	...	1·08
Ore *C*:			
Lumps	0·049	0·162	0·211
Rubble	0·033	0·658	0·691
Smalls	0·033	0·712	0·745
Ore *D*:			
Lumps	0·048	0·004	0·052
Rubble	0·058	0·093	0·151
Smalls	0·068	0·093	0·161

The second point is ore preparation. Much use has been made of this sphere of operations. Full advantage should be taken of pre-preparation before the ores are charged into the furnace, as this pays dividends in actual furnace operation. Ideally each ore should be prepared according to its density and reducibility, since it is feasible that refractory ores call for a smaller crushed size than soft reducible ores. It is natural that any furnace in which ores are coming down into the tuyere zone not fully reduced will never operate at its economic best nor will sulphur elimination be under control. The sintering of ore fines, especially with those ores which show higher sulphur contents in their fine grades, is a useful means of sulphur elimination external to actual furnace operation and takes a load off these operations. The sulphur variations with different size gradings in typical examples of ores used at Consett are shown in Table V.

It is a well-established fact that pyritic sulphur is efficiently removed by the sintering process. An example of this when sintering 100% pyrites is shown by the following analyses:

	Pyrites	Sinter
Iron, %	57·20	61·80
Silica, %	4·00	5·65
Sulphur, %	3·24	0·550
Lead, %	0·89	0·95
Zinc	0·91	0·96
Copper, %	0·50	0·475

Some doubts have, however, been expressed regarding the efficiency of sintering for sulphur removal when the sulphur exists in the ores to be sintered in the form of gypsum and barium sulphate. It is to be noted, however, that sintering is just as effective for sulphur removal when sintering these

Table VI

ANALYSES OF HIGH-SULPHUR ORES USED IN SINTERING TESTS (WORK AND HAMILTON)

	Minnesota Ore *A*	Michigan Ore *A*	Michigan Ore *B*
Iron, %	52·10	63·16	61·77
Silica, %	16·28	3·00	5·00
Alumina, %	2·46	1·63	1·63
Lime, %	...	1·30	1·70
Magnesia, % ...	...	0·22	0·36
Manganese, % ...	...	0·24	0·13
Phosphorus, % ...	...	0·21	0·18
Sulphur, %	0·255	0·55	0·81
Loss on ignition, % ...	...	2·20	1·30

Table VII

SINTERING TESTS ON HIGH-SULPHUR ORES (WORK AND HAMILTON)

Heat No.	Ore	Coke in Mix, %	Sulphur in Mix, %	Sulphur in Sinter, %	Sulphur removed, %
1	Minnesota *A*	4·3	0·255	0·013	94·9
2	,, ,,	4·7	0·255	0·013	94·9
3	,, ,,	5·6	0·255	0·012	95·3
4	,, ,,	6·1	0·255	0·024	90·6
5	,, ,,	6·5	0·255	0·015	94·1
6	,, ,,	7·4	0·255	0·046	82·0
7	,, ,,	8·2	0·255	0·056	78·0
8	Michigan *A*	4·0	0·553	0·174	68·5
9	,, ,,	4·5	0·421	0·086	79·6
10	,, ,,	5·0	0·462	0·183	60·3
11	Michigan *B*	4·0	0·737	0·041	94·5
12	,, ,,	4·5	0·901	0·026	97·2
13	,, ,,	4·5	0·756	0·031	95·8
14	,, ,,	5·0	0·767	0·059	92·3

ores as when sintering pyritic ores. In recent tests in America by Work and Hamilton[7] this is amply shown both in laboratory work and on full-scale trials. For the laboratory work synthetic ores were made, composed of a standard low-sulphur ore and sufficient sulphur-bearing material to bring the total sulphur in the mix to 0·518%. In one case pyrites were used as the sulphur-bearing material and in the other case gypsum. In the pyrites mix 94% of the sulphur was removed by sintering and in the gypsum 92% was removed. For the large-scale tests, which were conducted on a Dwight-Lloyd machine, three ores were chosen of high sulphur content, the sulphur existing predominantly in the sulphate form. The analyses of the ores are given in Table VI, and the sulphur removal during sintering is shown in Table VII.

The relationship between sulphur removal and the fuel in the mix was also clearly demonstrated in the tests, the efficiency of sulphur removal dropping as the fuel in the mix was increased. In addition, the effect of particle size in the mix on sulphur removal shows that sulphur removal is retarded with particle sizes above $\frac{1}{4}$ in. Similar results with regard to

Table VIII

ANALYSES OF SINTERS PRODUCED FROM VARIOUS MIXES

	Period 1	Period 2	Period 3
Iron, %	61·30	59·50	59·60
Silica, %	5·60	5·50	5·70
Sulphur, % ...	0·033	0·041	0·047
Phosphorus, % ...	0·166	0·262	0·180
Manganese, % ...	0·770	0·570	0·900
Ferrous oxide, % ...	12·00	14·30	12·60
Lime, %	3·20	4·50	3·20
Alumina, % ...	4·20	...	...

removal of sulphur during sintering have been experienced at Consett, where the sinter mixes vary considerably owing to the ores available, and where, over any three-months' period, the proportion of the higher-sulphur ores in the sinter mix may vary from 8 to 33%; at times the sulphur present is thus predominantly in the sulphate form and the mix sometimes contains up to 0·170% of sulphur. The sinter produced from the various mixtures varies little with regard to sulphur content, as shown in Table VIII.

Since the rate of production of any blast-furnace unit undoubtedly reflects upon the grade of raw materials used, it is reasonable to expect that any improvements in ore or coke quality, either physically or chemically, will benefit furnace operation. Any elimination of sulphur from ores that can be accomplished outside actual furnace operations is well worth while; this is especially the case where the ores show a tendency for increasing sulphur contents in their fines state.

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IRON AND STEELWORKS ENGINEERING

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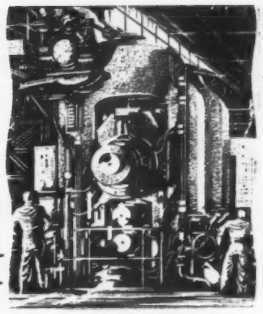

DESCRIPTION OF NEW PLANT

The Ferrostan Electrolytic Tinning Line at Richard Thomas and Baldwins, Ltd., Ebbw Vale

It was not until the late war that the production of electrolytic tinplate increased to substantial proportions, and this was mainly brought about by the necessity to reduce the consumption of tin.

In view of the rapid progress in this method of tinning, the Directors of Richard Thomas and Baldwins, Ltd., decided to instal an electrolytic tinning line at Ebbw Vale.

Foundation work commenced on 14th January, 1946, and the first strip ran through the line in April 1947.

The description of the plant and its installation is divided into four parts :

Part I—Outline Description and Operation of Plant.
Part II—Civil Engineering Aspects.
Part III—Mechanical Engineering Features.
Part IV—Electrical Engineering Features.

In setting it out in this way it is regretted that some overlapping of information is unavoidable.

Part I—OUTLINE DESCRIPTION AND OPERATION OF PLANT

DESCRIPTION OF THE PROCESS

The production of tinplate in continuous strip form has been a possibility since the advent of wide strip steel rolling. The use of electrolysis has now supplied the means of making the possibility a commercially accomplished fact. This achievement is the result of very extensive researches for which much credit must go to the industrialists of the U.S.A. The line now in operation at Ebbw Vale is a Ferrostan line developed by the Carnegie-Illinois Steel Corporation in collaboration with the Wean Engineering Company, Inc., and Messrs. John Miles and Partners (London) Ltd.

The Ebbw Vale line represents one of the main types of plant now being used for the production of electrolytic tinplate. Although these lines differ substantially in design, the processing treatments involved are essentially the same. It is customary to refer to these lines according to the type of electrolyte being used, and for the most part, the development of the main types of equipment was based on the particular type of electrolyte which independent research has made available. In the Ferrostan line the acid stannous sulphate electrolyte is used.

A general view of the line from the entry end is given in Fig. 1, and a flow diagram is shown in Fig. 2.

Plating

The first essentials of the coating are that it must be firmly adherent to the base metal and that it should present a fine uniformly grained surface. The most important single factor upon which these requirements depend is the value of the current density employed. It is found that spongy, loosely adherent coatings are produced when the current density employed is above a certain maximum limit. Unsatisfactory coatings are also obtained when the current density is too low. In both cases such coatings will not melt satisfactorily when the tinplate is given a subsequent flow-brightening treatment. The satisfactory working current-

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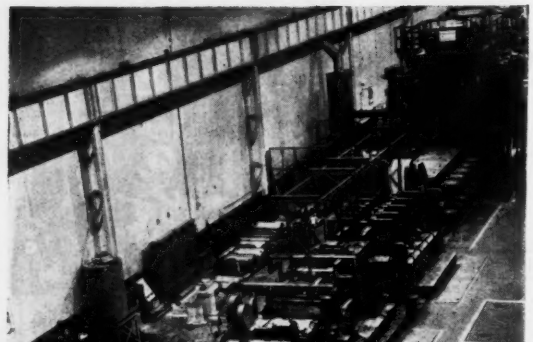


Fig. 1—General view of the Ferrostan electrolytic tinning line, from the entry end

density range of the Ferrostan electrolyte extends from about 100 to 300 amp./sq. ft. These limits, however, are not rigidly fixed and to a certain extent can be moved by making alterations to the electrolyte.

For the same weight of coating per unit area, the actual current density employed is directly proportional to the speed of operation. For instance, if the operating speed is 600 ft./min., compared with, say, 300 ft./min. the strip will be receiving the coating for exactly half the time. This means that the total current would have to be doubled, which in turn would involve running at double the current density. The maximum speed of operation is therefore to a large extent governed by the current-density limitations of the electrolyte. The plating range of the Ferrostan electrolyte has allowed the line to be designed so that a speed of 600 ft./min. can easily be obtained when making tinplate with 0·5 lb. per basis box coating, the comparatively short length of 40 ft. being sufficient for the total plating path.

To save floor space the plating passes of the Ferrostan line are arranged in an up-and-down or serpentine fashion, with the plating being carried out when the strip is in a vertical position. The plating bath consists of four separate rubber-lined steel tanks ; the bottom of each is equipped with a non-conducting rubber sink roll. Five chromium-plated copper conductor rolls are situated immediately above the tanks so that the strip proceeds vertically through the tanks when it is directed over the conductor rolls and under the sink rolls. The tin anodes which are used to replenish the tin content of the electrolyte are suspended vertically inside the tanks on both sides of each pass of the strip. This arrangement allows for four loops or eight strands or passes to be exposed to the tin anodes during the strip's progress through the bath, the effective length of one pass being 5 ft.

The supply of direct-current electricity to the bath is produced by two sets of motor generators which can generate a maximum total of 45,000 amp. The positive poles of the generators are connected to the anodes *via* copper bridges from which the anodes are suspended. The negative poles are connected in common with the five conductor rolls which are in contact with the strip.

Owing to the substantial amount of heat generated by the passage of the large currents employed it is necessary to cool the electrolyte if it is to be maintained at the required operating temperature. For this purpose the electrolyte is pumped from a 9000-gal. capacity tank through each of the four tanks in a closed circulating system. On its return to the tanks it is passed through one, two, or three water coolers to reduce its temperature to the required level. The temperature is automatically controlled through an electrically operated flow valve inserted in the cooling-water line. The electrolyte circulation also helps to prevent too rapid changes in the electrolyte composition during its passage through the process tanks. Circulation is normally maintained at about 400 gal./min., *i.e.*, 100 gal./min. through each tank.

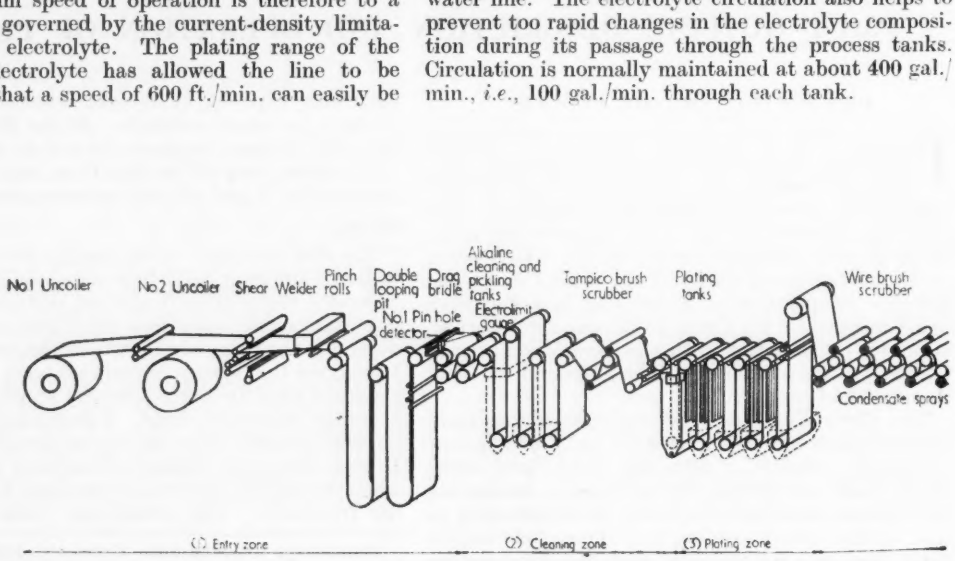


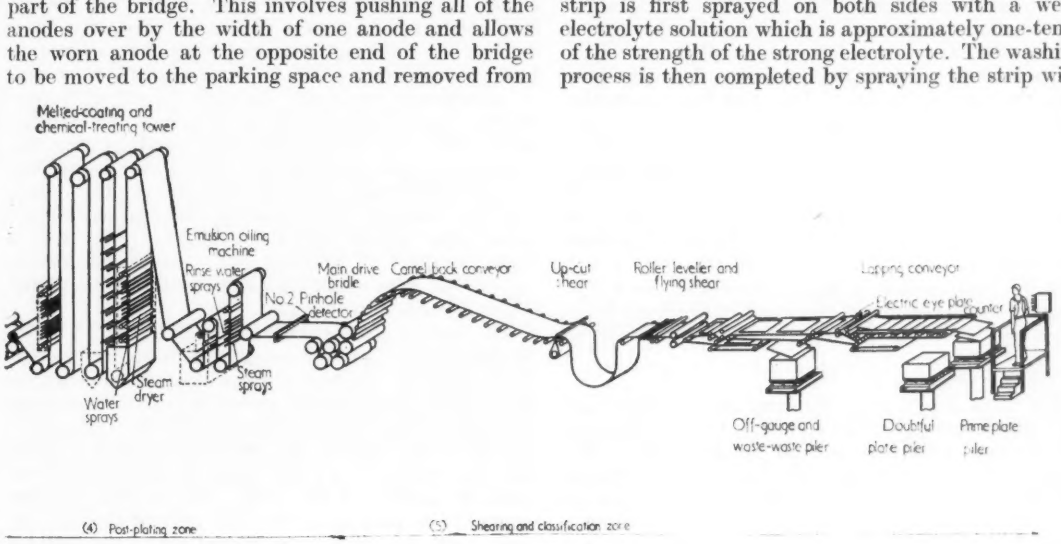
Fig. 2—Flow diagram of the Ferrostan

The anode practice employed on the line has an important bearing on the quality of the tinplate produced. To present a clear picture of the requirements it might perhaps be assumed that there is a single flat anode on each side of the strip, the same width as the strip and parallel to it both vertically and horizontally. Two considerations would prevent such an arrangement from giving uniform current distribution over the sheet. In the first place, the electrical resistance of the strip is sufficient to cause an appreciable IR drop down the strip, and since the current is fed from the top the current density would be higher at the top of the pass than at the bottom. This is largely overcome by tilting the anode so that it is closer to the strip at the bottom than at the top. The exact distances maintained are $1\frac{1}{8}$ and $1\frac{3}{8}$ in., respectively, which values increase by 0·1 in. with the wearing of the anodes. The second consideration is a high current density at the extreme edges of the strip owing to the tank being wider than the strip and anode and thus permitting lines of current flow between the anodes and cathodes to bulge out at the ends of the electrodes. This effect is reduced somewhat by making the anode a little narrower than the strip although if carried out too far a low current-density area will result on the part of the strip extending beyond the anode, except of course at the very extreme edges. The optimum extension of the strip beyond the anode is taken as $\frac{1}{2}$–$\frac{3}{4}$ in. For these reasons and also because of changing widths of strip and the desirability of renewing anodes without shutting down the line, a number of 3-in. wide anodes are substituted for a single anode on each side of the strip. To make the changing of anodes progressive, new anodes are introduced at one end of each anode bridge and worn ones are removed at the other end. Insulated parking spaces are provided at each end of each pass in which new and used anodes can hang. At regular intervals, determined by the rate of production, new anodes are pushed into the operating part of the bridge. This involves pushing all of the anodes over by the width of one anode and allows the worn anode at the opposite end of the bridge to be moved to the parking space and removed from the bath. The sides of the machine from which new anodes are fed are alternated with each bridge; thus the plate on each side of the machine is coated from an equal number of new and used anodes. Since there is an appreciable reduction in thickness between a new and a worn anode, the anode bridges are adjusted so that the actual working face of the anodes across the pass is parallel to the strip. Anodes are normally pushed after every successive 0·1 in. of wear. With 3-in. wide anodes this requires that the off-set of the bridge from being parallel to the strip should be 1 in. in a width of 30 in.

The Electrolyte

The Ferrostan electrolyte consists of a solution of stannous sulphate in an aqueous solution of isomers of phenol sulphonic acid. The satisfactory plating range of the electrolyte and the grain refinement of the tin coating, however, are very largely dependent on an additional agent. The chemical complexity of this compound disallows control by chemical analysis and resort is made to physical testing of the electrolyte using the Hull cell plating technique. The results of this test indicate the position of the satisfactory plating range and provide information with regard to the quality and regularity of the additions which should be made to the electrolyte. Oxidation of the stannous salt to the stannic state is minimized by reducing as far as possible any turbulence which might be encountered in the electrolyte.

The plated strip when leaving the bath carries with it a substantial amount of expensive electrolyte. If this electrolyte were allowed to be carried out of the line, the loss entailed would be prohibitive. This coating of the electrolyte would also give rise to extensive yellow stains on the surface of the strip. As much as possible of this drag-out is therefore removed and reclaimed for further use. For this purpose the strip is passed through a tank almost identical in design to the plating tank in which the strip is first sprayed on both sides with a weak electrolyte solution which is approximately one-tenth of the strength of the strong electrolyte. The washing process is then completed by spraying the strip with



electrolytic tinning line

steam condensate which is itself removed finally by passing the strip through a system of rubber squeegee rolls. The rate of flow of the condensate is adjusted so that the weak electrolyte is maintained at a constant analysis. Both weak electrolyte and condensate washings are circulated through a closed system which incorporates a circulating tank fitted with a constant-volume device. This device automatically bleeds off the excess volume which is pumped back into the main electrolyte system. The consequent increase in volume of the main solution is finally taken care of by evaporation in a continuous-type vacuum evaporator, the rate of evaporation being controlled to equal the rate of dilution in the drag-out recovery system.

DESCRIPTION OF THE LINE

The line can be conveniently divided into five main zones (*see* Fig. 2) : (1) Entry zone, (2) cleaning zone, (3) plating zone, (4) post-plating zone, and (5) shearing and classification zone.

Entry Zone

The entry zone includes two uncoilers which are capable of handling coils of up to 30,000 lb. in weight. The uncoilers are of the new expanding-reel type which greatly reduce scrap loss at this stage, and each is connected to a 5-h.p. motor which normally acts as a drag generator but which may also be used to jog the coil in either direction. The steel is fed from the coil by means of pinch-roll units into a double electrically operated crop shear which is used to square-off the leading and trailing ends of coils. The trimmed coil ends are welded in an automatic welder equipped with air-operated strip clamps. When a weld is to be made the line speed is reduced to 350 ft./min. and the entry zone is stopped. The trailing end of the strip is then cropped and joined to the previously cropped leading end of the new coil by means of a double seam weld. The whole of this operation normally takes about 12 sec.

A two-high pinch roll unit using a 15-h.p. drive delivers the strip into a looping pit. This pit which is approximately 50 ft. deep separates the entry zone from the rest of the line. The strip loops normally extend to the bottom of the pit and act as a reservoir for the processing part of the line whenever it is necessary to stop the entry zone for a welding operation. The exact position of the loops during normal operation is controlled by a set of photo-electric cells located near the bottom of the pit. These cells control the loops by altering the speed of the entry pinch rolls. A limit switch is also located near the top of the pit to stop the line in the event of the loops being consumed before the welding operation is completed.

Cleaning Zone

The strip passes from the loop into a drag-bridle unit which maintains the necessary tension throughout the line. The bridle is made up of four 19-in. dia. rubber rolls connected through a gear box to a 50-h.p. variable-voltage D.C. motor which is used as a drag generator. The small initial back tension required is created by passing the strip over a solenoid slab magnet as it emerges from the looping pit.

Before plating it is of fundamental importance that the strip surface be completely free from grease, oxides, and other surface blemishes which would interfere with the adhesion and appearance of the coating. To satisfy these requirements the strip is subjected to degreasing and pickling treatments. With speeds up to 600 ft./min. very little time is available for these operations and to accelerate the treatments electrolytic degreasing and pickling methods are employed. The cleaning tanks, which are situated between the drag-bridle unit and the plating tanks, are very similar in design to the plating tanks, being fitted with anode bridges carrying steel anodes similar in design to the tin anodes of the plating tanks. The strip is guided into the degreasing tank as it comes from the drag bridle. The alkaline degreasing solution which is maintained at about 200° F. is circulated through the processing tank from a 500-gal. storage tank. Normally about 5000 amp. are passed through the cell to give a current density of 100–150 amp./sq. ft. Following the degreasing operation the strip passes into a second tank in which the surface of the strip is subjected to a cold-water rinse and a mechanical brushing which is accomplished by means of electrically driven brush rolls. Next, the strip passes through the electrolytic pickler where it is treated with a dilute solution of sulphuric acid. The current densities employed are similar to those used in the electrolytic degreasing. Before arriving at the plating tank the acid remaining on the strip surface is washed away by directing the strip through a number of cold-water sprays. At the same time the surface is mechanically brushed with revolving tampico brushes which completes the cleaning treatment immediately prior to plating.

Post-Plating Zone

After plating, the strip has a white mat finish which in no way resembles the appearance of hot-dipped tinplate. Two alternative treatments can be given to the strip to brighten its appearance. The first is wire-brushing which was developed primarily as a method of finishing unmelted strip to produce a uniform appearance and to overcome the tendency of unbrushed, unmelted coatings to show fingerprints. The brushing is done by means of very fine nickel–silver wire brush rolls which produce very fine scratches in the tin surface. If properly controlled no appreciable amount of tin is removed. The necessity for brushing, however, has been largely eliminated since the advent of flow-melting. The velvet finish obtained by brushing has a certain decorative appeal and very small amounts of electrolytic plates are still finished in this way.

The second alternative finish is obtained by flow-melting and is now the recognized finish for electrolytic tinplate. As well as enhancing the appearance flow-melting has been the means of greatly improving the solderability and corrosion resistance of the plate. As the name implies, flow-melting involves heating the tin coating to a point where it melts and flows over the surface of the strip. The melting is done primarily by passing an electrical current through the strip itself, causing it to be heated above the melting point of tin. This is accomplished by passing the

strip around two conductor rolls at the bottom of the melted-coating tower. Between these rolls the strip passes over a third roll some 20 ft. above the conductor rolls. This third roll, called the transite roll, is a non-conductor of electricity and is at the same time resistant to heat. The amount of current used is adjusted so that the coating does not melt until after it has passed over the transite roll. During its passage between the two conductor rolls the strip is enclosed in an insulated muffle furnace equipped with strip heaters which maintain the furnace temperature at about 250° F. Some heat is transferred from the muffle to the strip, especially near the entry end where the strip is relatively cool, but this represents only a small percentage of the total power used for heating. Its main purpose is to reduce heat losses through radiation. To prevent discoloration the second conductor roll is immersed in a tank through which cold water is circulated so that the strip is quenched immediately after melting.

It is essential for the strip to be dry before passing round the first conductor roll. Wet strip entering the melting unit would reduce the efficiency, since some of the power would be consumed in evaporating the water. The strip is therefore passed through rubber squeegee rolls and a steam drier before it enters the melting zone.

During the baking of electrolytic tinplate at elevated temperatures after lacquering or lithographing, or during long periods of storage, the surface of the plate is often subject to yellow discoloration. This discoloration is caused by the formation of a visible tin oxide film. The tendency to discolour is very greatly reduced when the plate is treated with a very dilute solution of chromic acid. The action of the solution, which is an oxidizing agent, is to remove at least partially the porous oxide film already on the plate owing to the action of atmospheric oxygen and also to form on the surface a new oxide which although invisible is apparently much less porous than the film previously present. Owing to the less porous nature of this chemically formed tin oxide, atmospheric oxygen cannot reach the underlying tin surface as readily and the plate having such a protective film has little or even no tendency to discolour. In addition to this, chemically treated plate affords a much greater resistance to corrosion.

Following the flow-melting, the strip is passed through a tower in which it is sprayed with the chromic acid solution. The solution is maintained at about 200° F. and is pumped from a reservoir tank to the tower sprays from where it is passed down the strip into the processing tank. An overflow is provided near the top of this tank from which the solution is returned by gravity to the reservoir tank below. The excess chromic acid remaining on the plate as it leaves the tank is removed by water sprays and the strip is dried ready for the next operation.

When the first commercial electrolytic tinplate was produced it appeared that the necessary processing would have been completed after chemical treating. At this stage the plate was dry and completely free from oil in contrast to the slightly oily surface of hot-dipped tinplate. It was soon realized, however, that the lack of an oiled surface made handling very difficult. The dry surface also afforded little or no lubrication to the dies used in subsequent fabricating operations. It was necessary therefore to simulate further the characteristics of hot-dipped tinplate by applying a fine oil film. This was first accomplished in a specially designed branner–oiler which was capable of working at speeds up to 600 ft./min. It was soon superseded, however, by the emulsion oiler which is now universally employed on Ferrostan-type lines. The treatment consists of spraying a weak homogenized emulsion of cotton-seed oil in water on to the strip and removing the excess emulsion by passing the strip through rubber squeegee rolls. The strip is then dried by passing it through a steam drier and finally between a series of hot-air sprays. The emulsion oiler is installed immediately after the chromic acid tower and marks the end of the processing zone of the line.

The strip is pulled through the line from the looping pit by the main-drive bridle which is a five-roll machine similar in design to the entry drag bridle. It is powered by a 75-h.p. D.C. variable-speed motor which is used to control the speed of the line at any predetermined figure.

After leaving the drive bridle the strip is ready for shearing and classification.

Shearing and Classification Zone

The strip is end-sheared in a Hallden rotary shear which has a maximum speed of 600 ft./min. The maximum shearing speed is the real limiting factor of the maximum operating speed of the line. A small loop is maintained ahead of the shear to provide the necessary slack of tension, the loop being controlled photo-electrically in the same way as the loop in the entry part of the line.

After shearing, the tinplates are classified. The plates which are off-gauge or perforated are deflected into the first of three piler boxes. The off-gauge sheets are first detected by a flying micrometer which is installed at the drag bridle. The micrometer may be set to detect plates which are outside the specified weight limits and to operate a gate which deflects such plates into the first piler when they arrive at this point. There are two pinhole detectors on the line, one before and one after the processing zone. The first detects holes existent in the strip before they might possibly be filled in by the tin coating. The second detects holes which might have been brought about through electrical arcing at any of the conductor rolls. Both detectors are connected to operate the same deflector gate as the flying micrometer. The second piler box receives plates of doubtful appearance, the gate for this piler being manually controlled from either of two inspection positions. The third and last piler receives only prime plates ; these plates are automatically counted as they enter the piler and are finally removed ready for strapping and shipping.

Part II—CIVIL ENGINEERING ASPECTS

The foundations for the plant had to be installed in a portion of an existing building situated in the middle of the cold mill plant, and had to be constructed without causing any obstruction to the tinplate production that was being carried out in the adjacent buildings. Also, the excavation, some 25 ft. deep, had to be carried out without any disturbance to existing column foundations, floors, and foundations of other machinery. The overall size of the excavation was approximately 230 ft. long, 53 ft. wide, and 25 ft. deep, and in constructing the foundations the following quantities were handled :

Excavation	12,000 cu. yd.
Larsen sheet piling	20,300 sq. ft.
Bored piling	363 piles
Steel reinforcement	280 tons
Concrete work	4500 cu. yd.
Structural steelwork	36 tons

It was realized that the loading on the floor surrounding the electrolytic tinning machine would be severe, and the consulting engineers were asked to design the top floor with the side walls of the basement, supporting columns, etc., to carry a superimposed load of $\frac{3}{4}$ ton/sq. ft. on all parts of the floor. The whole of this weight was to be carried on piles

Fig. 3—View of foundations, looking south, showing sheet piling

underneath the basement floor, and for this purpose 363 piles of the bored-pile type, 15 in. and 19 in. in dia., including the piles under the electric overhead crane columns, were driven.

It was anticipated that there might be difficulty in obtaining any large quantity of structural steelwork at the time these foundations were being installed, and the work was therefore carried out almost entirely in reinforced concrete. Owing to the heavy superimposed load, a large quantity of steel reinforcement, totalling some 280 tons, had to be used.

To obviate any damage to adjacent buildings and foundations the contractors were instructed to surround the whole foundation with Larsen's No. 3 sheet piling. This was driven about 8 ft. into the soil below the basement floor level, so that when the excavation had been completed, there was still a depth of 8 ft. of original soil against the bottom of the sheet piles, which provided sufficient resistance to prevent any movement due to the earth pressure on the back of the sheet piling. The top of each sheet pile was secured by bolts passing through holes bored through the side walls of the building, and attached to steel pegs set into the floors of the buildings on either side of the electrolytic tinning line, and these prevented any movement of the top of the piles. The sheet piling can be seen in the left-hand background of Fig. 3.

When the sheet piling had been driven, the ground was excavated by a Diesel-driven excavator, and the spoil loaded into motor lorries for despatch to the spoil tip.

The concrete in the basement floor and in other parts where processing fluids might make contact, was protected by a layer of blue bricks set in a special acid-resisting cement. The concrete top floor was totally covered with wood blocks, 3 in. thick, set in bitumastic compound.

The scope and size of the foundations can be seen in Fig. 3 which is a view looking south, showing some of the side walls completed, and an intermediate floor being installed for supporting the pickling tank over the mechanical basement.

As a large amount of machinery and electrical equipment was installed in the basements, it was necessary to provide ample ventilation, and a ventilating plant was installed capable of supplying 75,000 cu. ft. of air per minute. This air is drawn by a fan through a tunnel (which had to be constructed under two adjacent building bays and under a railroad and highway) and through an air washer, and delivered into the electrical basement past the various machines, and afterwards through the mechanical basement and through a discharge tunnel, again under adjacent buildings, for exhaust to the atmosphere. Some portion of the ventilating air from the electrical basement could be discharged, through provision made in the top floor, to warm the air surrounding the electrolytic tinning line when required. The power for driving the fan on this ventilating equipment is supplied by a 100-h.p. motor.

The civil engineering work was commenced on 14th January, 1946, and the foundations, basement floors, intermediate floors, top floors, ventilating tunnels, etc., were completed by the following November.

Part III—MECHANICAL ENGINEERING FEATURES

INSTALLATION OF THE PLANT

The installation of the mechanical equipment presented interesting problems in setting out, lining, levelling, and squaring the many units in relation to each other, to enable the wide, light-gauge steel strip to be successfully tracked and located within the close limits necessary to produce an electrolytically tinned strip at high line speeds.

In addition to a side-trimming unit, which is separately installed, the line itself consists of the following units (*see* Figs. 1 and 2):

(1) Uncoiler
(2) Shear
(3) Welder
(4) Pinch rolls
(5) Looping pit
(6) Drag bridle, pinhole detector, and gauge
(7) Alkaline cleaning and pickling tanks
(8) Tampico brush machine
(9) Plating tanks
(10) Wire-brush machine
(11) Melted-coating tower
(12) Emulsion oiling machine
(13) Drive bridle
(14) Cut-off shears
(15) Roller leveller and flying shear
(16) Prime and reject piler units
(17) Ancillary plant, consisting of hydraulic and process pumping, storage, cooling, and treating equipment, located in the mechanical basement

The complete line was received from America in some 200 cases, varying in weight from 30 tons to a few hundredweights, and was so well packed that the only mechanical damage sustained was the fracturing of two pipe flanges.

On starting the actual erection the practice of fitting jack bolts to the bases of all machines was a considerable advantage, as a total of fifteen independent units, up to and including the rotary flying shears, had to be positioned so accurately on a 200-ft. line that about 500 ft. of continuous 30-in. wide strip, 0·010 in. and less in thickness, tracked perfectly and without wandering at speeds up to 600 ft./min. In this distance the strip passes over or under some 70 sets of rollers, through a total elevation from 50 ft. below ground level at the bottom of the looping pit to 24 ft. above ground level at the top of the melted-coating tower, and with only two sets of side guides throughout the entire 500 ft. of strip travel. The accurate positioning of many of the units was made more difficult by the considerable number of insulating plates, ferrules, and washers between the structural members, and between the bases of units and the foundations, wherever electrical current was applied to the strip.

The whole underground area of the line is occupied by large mechanical and electrical basements, in the former of which are situated the hydraulic equipment serving the various operations, such as coil-holder movements, etc., the electrolyte-circulating pumps, storage tanks, cooling and treating equipment, etc., all of which are connected to their respective units above ground by a large number of flexible rubber, rubber-lined, acid-resisting, or ordinary steel piping, to a total length of 7000 ft., varying in diameter from $\frac{1}{4}$ to 10 in. A view of part of this basement is shown in Fig. 4.

The task of construction was complicated by the fact that it had to be undertaken amongst the normal production units without interfering in any way with output or quality, and also the three divisions, mechanical, electrical, and civil, were all proceeding at the same time, which called for very close collaboration to ensure the necessary interlocking of activities.

MECHANICAL FEATURES OF THE LINE

It will be of interest to describe some outstanding mechanical features of the more detailed construction of the equipment of the electrolytic tinning line, and it can be said that the most up-to-date engineering practice was employed throughout, involving the use of chromium plating of roll bodies, alloy steels of all types, and plastics for certain girder sections, insulating liners, bushes, and roll shells serving the dual purpose of wear resistance and insulation.

In the transite roll above the flow-melting tower and the copper conductor rolls in the pickling and plating tanks, unusual construction methods were used. In the first instance, the roll body, approximately 16 in. in dia. and 42 in. long, is made of an asbestos-cement shell which is ground-finished to avoid marking the partially heated strip as it turns downwards at the top of the flow-melting tower, and in the second instance the roller is of copper with a chromium-plated body and is internally water-cooled to dissipate the heat caused by the high current flow. The complicated internal construction of this roller is illustrated in Fig. 5.

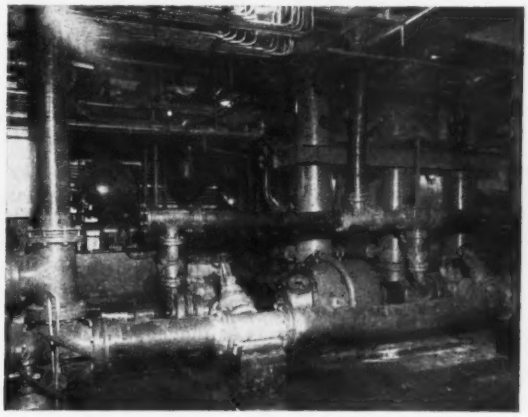


Fig. 4—Part of the mechanical basement

Most of the rollers throughout the line are statically and dynamically balanced and linked with **V** belts through P.I.V. gear boxes to ensure perfect synchronization of the peripheral speeds, which is of the

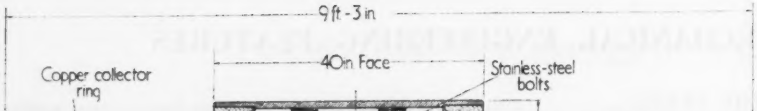


Fig. 5—Copper conductor rolls used in the pickling and plating tanks

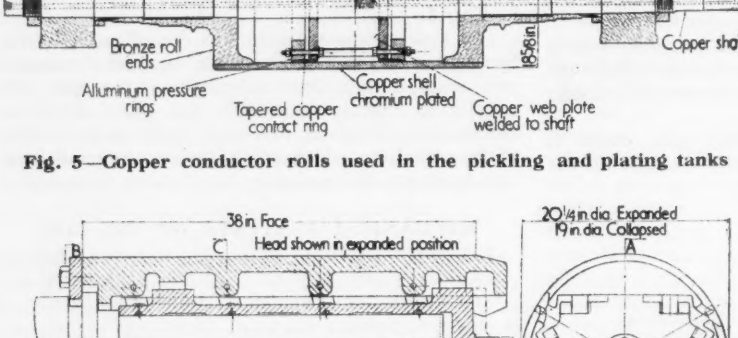


Fig. 6—Tandem pay-off reels in the uncoilers

utmost importance in the interest of surface quality of the strip, damage to which must be avoided throughout. The line commences with the uncoiler units where previously side-trimmed coils, of a maximum weight of 30,000 lb., are fed on to the two tandem pay-off reels (*see* Fig. 6). These reels are expanded and collapsed by compressed air for which a simple mechanism is employed, consisting of a series of links on a triangular mandrel coupled to three segments, the longitudinal edges of which are serrated to minimize damage to the inside laps of the coils. These coils can be centred to the line while paying off by movement of the entire uncoiler unit, which is mounted on slide rails and energized from the hydraulic system.

The electrically operated double up-cut shear, which has one set of knives to each reel, prepares the ends of the strip for welding while the previous coil is being fed through the line. To withstand the high tension applied to the strip the lapped ends are double-seam welded by a standard Taylor-Winfield machine.

A pair of pinch rolls pulls the strip off the reels through the shears and welding unit, and feeds it into the 50-ft. looping pit, which is fitted with a powered bridle so that a double loop can be operated. This pit provides the necessary storage to enable the strip to be welded without stopping the line.

A series of small fabric rollers and edge discs then guides the strip out of the pit, into the drag-tension bridle and through the attached pinhole detector and micrometer gauge. The initial drag is applied by passing the strip vertically over a powerful magnet covered by a fabric sheet, but the back tension is provided by the usual series of rubber-covered rollers geared to a drag generator.

In the alkaline cleaning and pickling tanks the strip is carried over copper conductor rolls, the liquid drag-out being prevented by soft rubber squeegee rolls.

Following this unit comes the tampico brush machine, which follows conventional design except that the strip-supporting rolls are rubber-covered, with the powered brush rolls alternately above and below so that each surface is thoroughly scrubbed.

The plating unit is mainly an electro-chemical problem. On the mechanical side items of note are the copper conductor rolls, in which internal water-cooling presents a difficult problem and robustness of construction is an important consideration, as they have to withstand heavy strip tension loads as well as the high current flow. On this unit the special

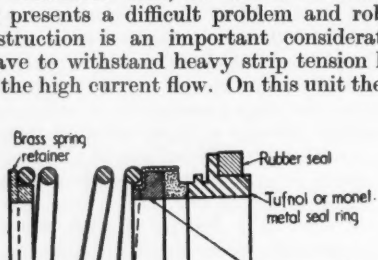


Fig. 7—Shaft seals fitted on the bottom rollers in the plating tank

shaft seals (*see* Fig. 7) on the bottom rollers are of the utmost importance in avoiding loss of the costly electrolyte. Loss by drag-out is taken care of by passing the strip through a tank containing dilute electrolyte, followed by sprays and squeegee rolls. Plastic liners and bushes insulate the roller pedestals, etc., from the machine frames, and spring-loaded rubber-covered rollers press the strip uniformly down on the conductor rollers to prevent arcing. The tin anodes are hoisted into position by a power hoist moving on an **H** beam.

Reverting to the electrolyte circuit, the following interesting points may be noted. The passage of the fluid through the plating tank, at approximately 500 gal./min., increases its temperature by 3–6° F., and this heat has subsequently to be removed by pumping through tubular heat exchangers, which are of quite normal construction with the exception that the tubes are of carbon material. The amount of water necessary to carry out the cooling is controlled by temperature-indicating and recording instruments operated directly through a thermocouple immersed in the electrolyte solution. The overflow from the dilute electrolyte enters the main system, raising the level in the main circulating tank, and a level control float in the circulating tank operates an evaporator system which removes the water from the electrolyte as required. The evaporator removes this water by boiling it off under a vacuum in a large cylindrical vessel, the amount evaporated being regulated by the amount of steam supplied to the heater, and the previously mentioned level-control float in the main circulating tank operates an automatic steam valve as required to maintain constant-level conditions.

It can be readily understood that a very complete system of interlocking automatic controls is essential in maintaining a balance throughout all this system, as the amount of incoming dilute electrolyte has to be balanced very carefully by the requisite supply of steam to the evaporator and also the flow of water to the ejector to obtain the necessary vacuum.

In the wire-brush machine the construction of the brush material is unusual and consists of 22,000 single strands of nickel–silver wire per square inch, which provides an almost continuous flexible surface at the roll periphery

Next in the line is the melted-coating tower, some 24 ft. in height, through which the strip passes up and down. In this unit are further examples of the previously mentioned copper conductor rolls, situated in the bottom of the spray and quench tanks, and the transite roll at the top.

The lubrication system adopted throughout the line consists of individual units interlocked so as to interrupt the power supply in case of any lubrication failure.

The emulsion oiling machine which follows is remarkable for the very fine oil spray delivered from the homogenizer, a standard machine used in the U.S.A., which is in effect a very highly finished small 3-throw hydraulic pump, discharging through stainless-steel nozzles at a pressure of 1000 lb./sq. in. to the oil-emulsion circulating pump.

The subsequent main-drive bridle consists of a series of rubber-covered rolls, approximately 19 in. in dia., round which the strip travels in a zig-zag path emerging finally through a pair of pinch rolls, of which the bite pressure is applied by air cylinders, and from there through the shallow looping pit in front of the Hallden roller leveller and flying-shear unit. This shear is of the rotary-drum type which, cutting up to 600 ft./min., sets the mechanical limit to the speed of the line. Lengths of cut vary from 18 to 41 in. and are adjusted to very fine limits by the P.I.V. gear.

The sheared tinplates are then delivered on to a rubber conveyor belt passing under a fabric roll from which they can be diverted by an automatically controlled gate down on to the off-gauge and waste-waste piler or the prime-plate piler as required.

The piling of cut plates at high speeds is made possible by the shingling process, *i.e.*, each succeeding plate is made to overlap the one ahead of it by varying the speed of the pinch rolls in relation to the conveyor belt. This is a most important function, as sheared tinplates of the lighter gauges can easily get out of control when running at high speeds.

Additional aids to the handling of these cut plates are slightly dished conveyor belts with powerful magnets underneath, which prevent any bouncing of the plate leaving the shingling roll. The lapped and dished plates are fed into the piler boxes in a continuous stream, falling gently, due to compressed air jets, in a neat pile on to a stillage which lowers as the stack grows. Air-hydraulic rams provide the action and eventually place the laden stillages on to gravity roller tracks, down which they are pulled by means of air cylinders, ready to be picked up by fork battery tractors.

Part IV—ELECTRICAL ENGINEERING FEATURES

ELECTRICAL EQUIPMENT

With the exception of the 11-kV. switchgear, power transformers, main sub-station, 440-V. switchgear, cables, conduits, and wiring accessories, the electrical machinery and equipment was supplied by the Wean Engineering Company, Inc., subcontracting to electrical manufacturers in the U.S.A.

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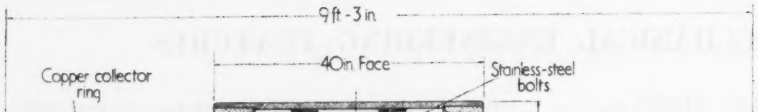

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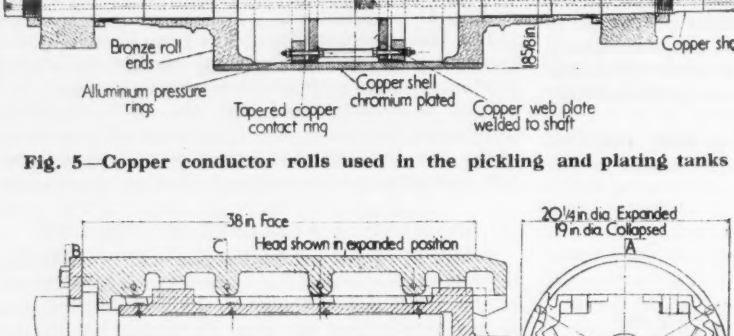

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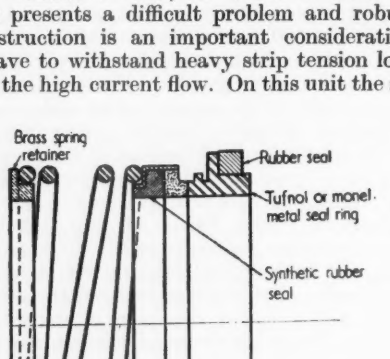

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Part IV—ELECTRICAL ENGINEERING FEATURES

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POWER SUPPLY

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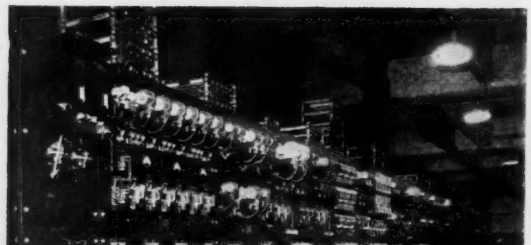


Fig. 8—Main D.C. control panel in the electrical basement

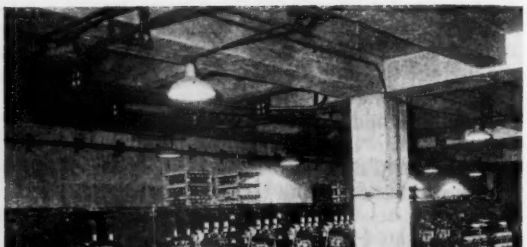


Fig. 9—Main A.C. control panel in the electrical basement

works sub-station at 11 kV. to a site sub-station, terminating in a stonework cellular-type switchboard equipped with vertical isolating oil circuit-breakers of 250-mVA. breaking capacity, *via* an outdoor oil-cooled current-limiting reactor of the core type, designed to have a reactance of 4% at full load throughput current and suitable for reducing the short-circuit fault value from 765 to 200 mVA.

The 440-V., 3-phase, 50-cycle supply is taken from the site sub-station *via* two 2000-kVA., 11,000/400-V. Delta–Star transformers, one acting as a standby to the other, and thence to the electrical basement, which is situated immediately beneath the pickling, plating, brushing, reflow, and shear units.

A 250-V. D.C. supply is taken from the cold-mill service switchboard to furnish power for the constant-potential group of equipment, and in addition a 50-kW., 250-V. generator coupled to the 500-h.p. variable-voltage M.G. set provides a separate supply for excitation circuits.

Figure 8 shows the main D.C. control panel, the incoming panel being evident at the left-hand end, and Fig. 9 shows the main A.C. control panel, with the variable-voltage M.G. set and booster sets in the foreground. The incoming panel can be seen immediately to the left of the central pillar. These control panels are mounted in the electrical basement and are equipped with all the main D.C. and A.C. control gear for the operation of the electrolytic tinning line.

SUMMARY OF ROTATING EQUIPMENT

In the following table the rotating equipment is summarized under the headings : (*a*) Variable-voltage group, (*b*) constant-potential D.C. group, and (*c*) A.C. group.

(*a*) Variable-Voltage Group

Drive	Rating	Voltage	Speed, r.p.m.
Alkaline cleaning generator	60 kW.	12	500
Approach table	3/5 h.p.	230	575/2300
C.E.M.F. exciters	5 kW.	200	1455
Coil-holders, Nos. 1 and 2	5 h.p.	230	250/1200
Coil-holder generators (drag), Nos. 1 and 2	5 kW.	250	1450
Double-loop drive	0·75/3 h.p.	250	400/1600
Drag bridle	15 kW.	250	850/1150
Drag-bridle booster generator	7·5 kW.	125	1450
Drive bridle	60/75 h.p.	230	500/1500
Entry pinch rolls	15 h.p.	230	400/1600
Flying shear	60/75 h.p.	230	500/1500
Lapping pinch rolls	3/5 h.p.	230	575/2300
Main excitation generator	50 kW.	250	1500
Melted-coating saturating generator	10 kW.	30	1450
Motor-operated rheostats (line speed)	0·25 h.p.	230	1140
Motor-operated rheostats (plating generators)	0·25 h.p	230	1140
Off-weight piler conveyor	3/5 h.p.	230	575/2300
Plating generators, Nos. 1 and 2	120 kW.	16	300
Plating generators, Nos. 1, 2, 3, and 4	90 kW.	12	300
Plating-generators' exciter	50 kW.	250	1500
Pickling generator (anode)	24 kW.	12/24	600
Pickling generator (cathode)	60 kW.	12	500
Piler conveyor, Nos. 1 and 2	3/5 h.p.	230	575/2300
Tin-recovery generator	48 kW.	16	500
Variable-voltage generator *A*	75 kW.	250	1500
Variable-voltage generator *B*	75 kW.	250	1500
Variable-voltage generator *C*	75 kW.	250	1500

(*b*) Constant-Potential D.C. Group

Recirculating pumps, Nos. 1, 2, and 3	40 h.p.	230	850/1700

(*c*) A.C. Group

Air-blast circuit-breaker compressor	3 h.p.	440	1450
Air-washer pump	10 h.p.	440	1450
Alkali brush	10 h.p.	440	575
Alkaline pump	5 h.p.	440	1450
Alkaline cleaning M.G. set (motor)	100 h.p.	440	500
Anode hoists, Nos. 1 and 2	0·5 h.p.	440	...
Anode pickling M.G. set (motor)	40 h.p.	440	600
Auxiliary M.G. sets, Nos. 1 and 2 (motor)	30 h.p.	440	1450
Cathodic pickling M.G. set (motor)	100 h.p.	440	500
Centrifuge	5/2·5 h.p.	440	1450/725
Chromic acid circulating pump	15 h.p.	440	1460

Drive	Rating	Voltage	Speed, r.p.m.
Coil - holder hydraulic pumps, Nos. 1 and 2	15 h.p.	440	1460
Coil - holder lubricating pumps, Nos. 1 and 2	1 h.p.	440	1450
Coil-holder pinch rolls	2 h.p.	440	1280/48 (geared)
Condenser circulating pump	5 h.p.	440	1465
Dilute circulating pumps, Nos. 1 and 2	5 h.p.	440	1450
Double - cut pinch rolls, Nos. 1 and 2	5 h.p.	440	850
Double-cut shears, Nos. 1 and 2	7·5 h.p.	440	850
Drag - bridle lubricating pumps	1 h.p.	440	1450
Drive - bridle lubricating pump	1 h.p.	440	1450
Electrolyte make-up and circulating pumps, Nos. 1, 2, and 3	5 h.p.	440	1450
Electrolyte tin-recovery pump	5 h.p.	440	1450
Evaporator-system pump	5 h.p.	440	1450
Filter pump	1·5 h.p.	440	1450
Flying-shear oil pump	3 h.p.	440	960
Homogenizer	5 h.p.	440	1445
Iron salt agitator	2 h.p.	440	533
Leveller overshot roll	0·75 h.p.	440	650
Leveller roll adjustment, Nos. 1 and 2	0·75 h.p.	440	650
Looper-pit sump pump	7·5 h.p.	440	1460
Master lightening mixer	1 h.p.	440	1440/350 (geared)
Melted-coating saturating M.G. set (motor)	15 h.p.	440	1450
Melted-coating exhaust	5 h.p.	440	1445
Oil-emulsion drier	15 h.p.	440	2950
Oil-emulsion pump	5 h.p.	440	1445
Plating M.G. sets, Nos. 1 and 2 (motor)	500 h.p.	440	300
Pulsafeed	1/6 h.p.	110	...
Storage tank system pumps, Nos. 1 and 2	5 h.p.	440	1450
Tampico brushes, Nos. 1 and 2	15 h.p.	440	1460
Tin - recovery cell and syntron	⅓ h.p.	440	1425/0·3 (geared)
Tin - recovery M.G. set (motor)	100 h.p.	440	500
Variable-voltage M.G. set (motor)	500 h.p.	440	1500
Ventilating fan (basement)	100 h.p.	440	980
Welder cut-out shear	7·5 h.p.	440	850
Welder-head drive	1·5 h.p.	440	1440
Wire brushes, Nos. 1–10	15 h.p.	440	1460

With few exceptions, notably the smaller horse-powers, the motors were designed for 50 cycles instead of the standard U.S.A. periodicity of 60 cycles.

A schematic diagram of the electrical installation is shown in Fig. 10.

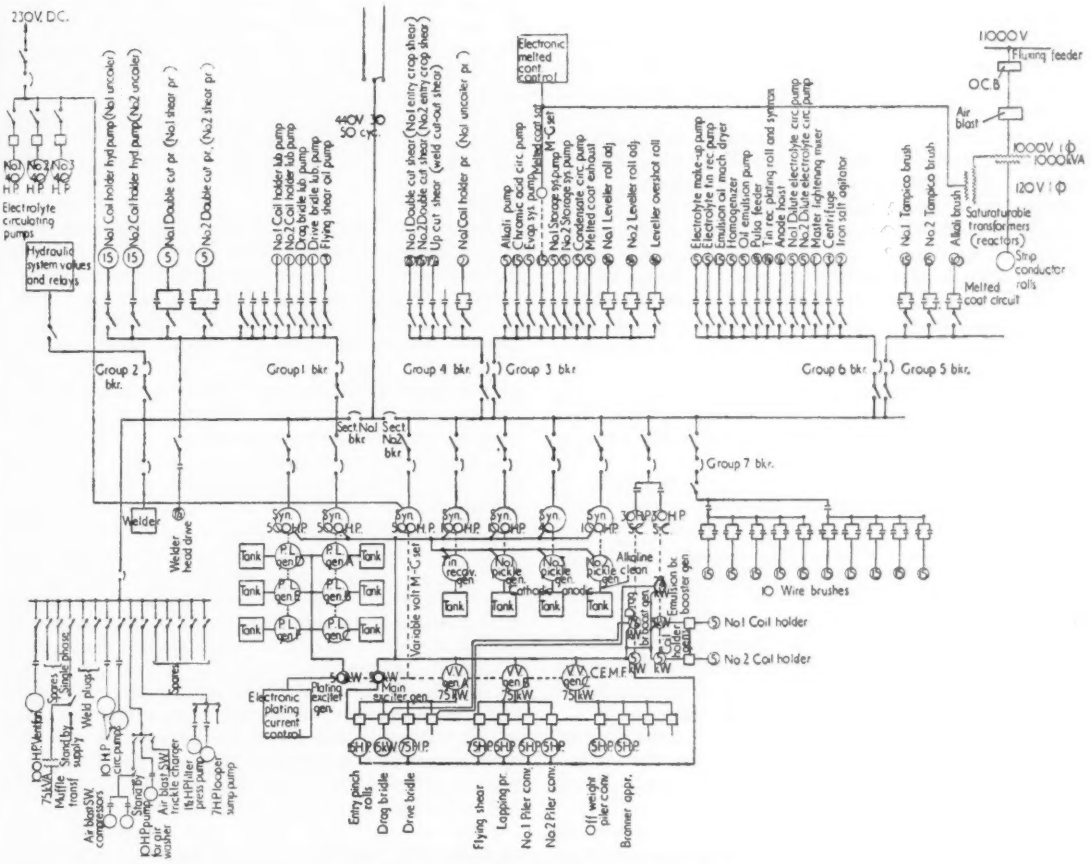


Fig. 10—Schematic diagram of circuits

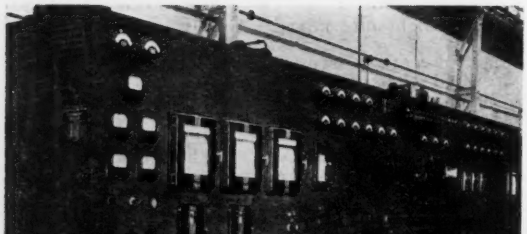


Fig. 11—Master-control station, situated opposite the melted-coating unit

CONTROL STATIONS

For controlling the electrolytic tinning line seven control stations are located at positions selected to afford the operators accessible and visual control of their respective sections.

The line-speed control push-buttons giving "low," "medium," and "high" speed selection, as pre-set on the master control station, are duplicated at five stations, while emergency-stop push-buttons are provided on six stations.

In addition, independent "jogging," both forward and in reverse, by means of push-buttons suitably located, is provided on the following drives: Uncoilers, double-cut pinch rolls, coil-holder pinch roll, entry pinch roll, double loop drive, drag bridle, drive bridle, flying shear, lapping pinch rolls, piler conveyors Nos. 1 and 2, approach table, and off-weight piler.

The D.C. motors are reversed by armature circuit contactors except for the flying shear to the off-weight piler drives, which are reversed by the appropriate Ward-Leonard generator shunt field.

Figure 11 shows the master control station which is positioned opposite the melted-coating unit, and it is from this station that major adjustments and metering are effected.

FEATURES OF CONTROL

Reference to Fig. 2 will indicate the physical position of the motions and equipment briefly explained from the electrical viewpoint.

Uncoilers

Each uncoiler mandrel is independently driven, only one being selected for tandem operation, the other being available for loading and making-ready for the end of the coil of strip being processed.

The uncoilers can be "jogged" (inched) independently in forward or reverse, or run in tandem with the rest of the rotating equipment taking the strip through to the final piling operation.

An armature change-over switch is provided for each uncoiler so that when the strip coil is put on the mandrel to pay off either over or under, the uncoiler still generates in tandem or responds to the "jog" control in the correct direction.

In tandem, the uncoiler motor is brought up to speed under Ward-Leonard control, and the coil-holder generator shunt field obtains its supply from a motor-operated potentiometer, the movement of which is regulated from the line-speed control circuit, as explained later.

Connected in series with the shunt field of the uncoiler motor is a voltage regulator of the Brown-Boveri pattern, the operation of which depends upon the action of its three coils, namely, inertia compensation, drag adjustment, and main operating. These three coils are adjusted to compensate for the inertia of the strip coil on the mandrel during acceleration and deceleration and to maintain stable back-tension of the strip throughout the uncoiling range of the coil.

Double-Cut Pinch Rolls and Shears

There are two double-cut pinch rolls; one feeds the strip from coil-holder No. 1 and the other from coil-holder No. 2. The motor-driven rolls are pneumatically lifted, the supply being regulated by an electrically operated solenoid valve.

The double-cut shears, one for each uncoiler, are controlled in a standard manner, *i.e.*, from push-buttons and a cam limit switch, chain-driven from the shaft of the driving motor. The control is so arranged under automatic selection that, concurrent with the shear operation, the entry pinch-roll motor turns sufficiently to advance the sheared tail of the strip to the correct position on the anvil of the welder. The distance the strip travels is governed by a pin-wheel timer, which is adjustable to close limits.

Welder

The welder is a 48-in. Taylor-Winfield, roller seam strip welder. Normally rated at 50 kVA., 440 V., single phase, the welding transformer has a primary winding designed to provide sixteen values of secondary current varying between 14,700 to 36,500 amp., the load depending, *inter alia*, on the speed of weld, thickness of material, and type of weld, *i.e.*, continuous or intermittent, the latter being accomplished by an adjustable current interrupter providing a rapidly recurring current impulse.

The transformer is water-cooled, as also are all the secondary terminals and the welding wheels. The welding wheels are manufactured from hard copper alloy forgings of high electrical conductivity designed to resist flattening and softening under pressure, especially at temperatures between 200° and 800° F.

For operation with the electrolytic tinning line the control of the welder has been modified to include semi-automatic features. The strip of a new coil is advanced by the jog operation of the double-cut pinch rolls to the work anvil of the welder, the travel being sufficient to overlap the end of the preceding coil; operation of a push-button energizes a solenoid-operated valve to bring a work-clamp bar down, thus holding the two ends of the strip together. The clamp bar, in its descent, closes a limit switch which operates another solenoid and valve and brings the head, carrying the welding wheels, down to the work. Standard pressure on the work is 900 lb./sq. in., with

a maximum of 1150 lb./sq. in. The work clamp, in its descent, also operates a further limit switch which initiates the circuit to the forward contactors of the 1·5-h.p. head traverse motor to move the welder head through a screw-and-nut drive.

Intermittent seam welding is employed for joining the ends of the strip together. The current is controlled by two ignitron tubes, cross-connected to give full-wave passage, timed for the "on" and "off" cycle by an electro-pneumatic timing unit. The firing circuit of the welder is initiated by a separate wheel contact on the welder head energizing the auto-firing relay, through an earth return circuit, when it makes contact with the strip. When the welding wheels leave the strip, the earth return contact energizing the auto-firing relay open-circuits and the welding current ceases to flow, at the same time de-energizing the air-valve solenoids for the head, work clamp, and stop bar. The head, on lifting, operates a limit switch to initiate the circuit for the reversing contactors of the head-traverse motor and the head is brought back to its original position.

Completion of the welding operation makes ready the entry end for processing and the electrolytic tinning line can run up to speed in tandem control provided that the double-cut pinch rolls are released.

Entry Pinch Rolls

The entry pinch roll is grouped together with the drag and drive bridles, the speed of these three machines being under Ward-Leonard control up to the lower speed range, and from the lower speed range to maximum speed by field weakening. Field weakening of the motors is accomplished by a C.E.M.F. booster in series with the supply to the shunt fields.

Voltage control for the Ward-Leonard generator and the C.E.M.F. booster is by a motor-operated potentiometer supplying their shunt fields, movement of which is explained latter under Speed Control.

Strip from the entry pinch roll is fed into a looping pit, 50 ft. deep, the loop being duplicated over a separately driven intermediate roll so as to make approximately 200 ft. of strip available for processing during the time interval when the entry end is stopped to enable another coil to be welded on to the preceding strip end.

With the electrolytic tinning line running at speed the loops are maintained at their predetermined levels, or height from the pit bottom, by the aid of photo-electric cells, and any variation in speed of the entry pinch rolls or double-loop roll will cause the strip to expose or obscure the beam of light directed on the photo-electric cells; these *via* their respective group of relays vary the strength of the shunt field of the motor affected and so cause its speed to increase or decrease accordingly.

Drag Bridle and Drive Bridle

The speed of the drag bridle is controlled in the same way as for the entry pinch roll, but when running at the selected line speed it acts as a drag generator, the amount of drag current being controlled by a 7½-kW. booster generator in series with the drag-bridle armature.

The booster-generator shunt field is controlled by a Brown-Boveri-type regulator similar to that supplied to the uncoiler. An adjusting coil on the regulator, which is varied by a Vernier rheostat at the main control station, moves the regulator so as to make the booster apply a voltage in series with the back e.m.f. of the drag bridle, the sum of which is greater than that of the Ward-Leonard controlled generator and will therefore cause regeneration.

An operating coil on the regulator is fed from the drop voltage across a series resistance in the drag-bridle armature; this coil operates to keep the drag current constant as in the uncoiler. Also controlling the movement of the regulator is an inertia compensating coil, operating in a manner similar to the uncoiler.

Control of the drive bridle is exactly the same as for the entry pinch rolls.

Flying Shear, Lapping Pinch Rolls, Conveyors, etc.

In tandem control the flying shear is grouped together with the lapping pinch rolls, piler conveyors Nos. 1 and 2, the off-weight piler, and the approach table. As in the previous sections of the electrolytic tinning line, the speed is by Ward-Leonard control up to the lower speed range, and by field weakening up to maximum designed speed.

The voltage of the Ward-Leonard generator is varied by a motor-operated rheostat, the movement of which is controlled by the line-speed circuit. The shunt fields of this last group of motors are connected to the same supply as the previous group, *i.e.*, in series with the C.E.M.F. booster generator, and separate rheostats for each shunt field are mounted at the appropriate control stations.

Before entering the flying shear, the strip passes into a small looping pit, the height of the loop again being controlled by photo-electric cells. These photo-electric cells operate a group of relays which cut-in or cut-out a series of resistances in the Ward-Leonard generator shunt field.

The lapping pinch rolls, the piler conveyors Nos. 1 and 2, and the approach table are controlled in a similar manner to that described for the flying shear, and control of the weld cut-out shears is similar to that described for the double-cut shears.

Speed Control

The electrolytic tinning line is brought up to base speed by Ward-Leonard control, the generators supplying the driving motors in the variable-voltage group, and from base speed to full speed by shunt field weakening, *via* the C.E.M.F. booster generator.

The raising of the Ward-Leonard generator voltage and the weakening of the excitation to the shunt fields of the drive motors is controlled by a motor-operated rheostat, as explained under the section dealing with separate motor circuits. The motor-operated rheostat can be controlled manually or automatically.

For manual control the speed of the electrolytic tinning line is controlled from a speed master switch mounted at the main control station. This master switch when at the "fast" position energizes the "fast" directional contactors in the armature circuit of the motor-operated rheostat. The motor-operated rheostat will move from the "off" position and will continue to turn as long as the master switch is

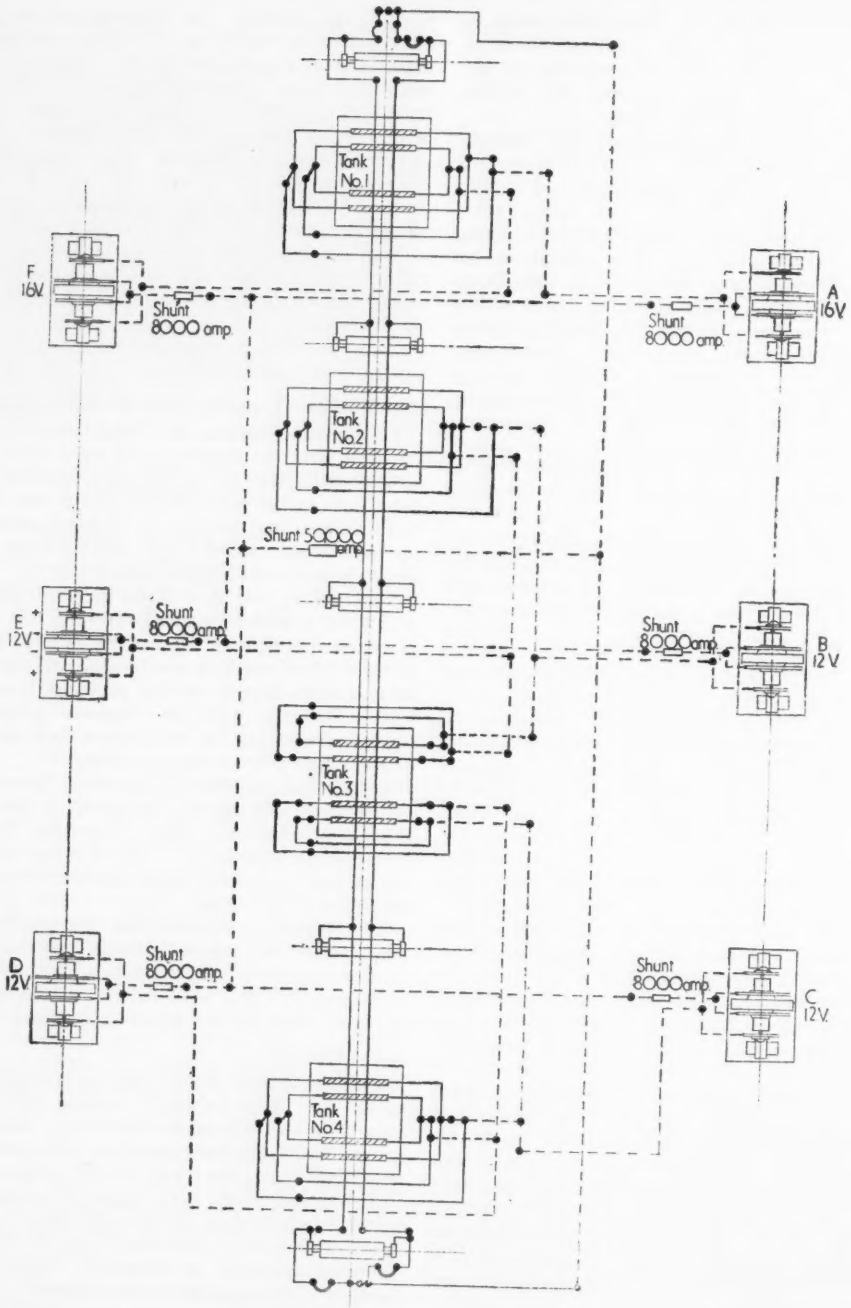


Fig. 12—Diagram of plating circuit

held in the "fast" position. Releasing the master switch de-energizes the directional contactors and the motor-operated rheostat stops, is held, and the electrolytic tinning line continues to run at a speed determined by the position of the motor-operated rheostat.

The master switch when at the "slow" position reverses the motor-operated rheostat and so decreases the speed of the tinning line.

For automatic control, push-buttons giving "low," "medium," and "high" speed selection, as pre-set on the main control station, are duplicated on five of the control stations.

The auto-speed control circuit comprises a tacho-

generator driven from the drive bridle, the output of which is connected across a number of rheostats forming a potentiometer. Connected across a section of this potentiometer is the operating coil of a Brown-Boveri-type regulator, the contact arm of which is spring-loaded to a position so as to energize the " fast " armature directional contacts of the motor-operated rheostat.

With the numerous interlocking features closed, all safety and protective devices intact, and the main contactors for the motors, etc., closed, a supply is given to a sector of this regulator and by its spring-loaded position the motor-operated rheostat is energized and turned, so exciting the Ward-Leonard generators to increase the electrolytic tinning line speed up to the " low " speed tandem value.

The tacho-generator, driven from the drive bridle, will begin to generate and cause current to flow through the potentiometer. From the voltage drop across a section of this potentiometer the operating coil of the Brown-Boveri-type regulator is fed and as the line speed increases the tacho-generator voltage will continue to rise until the voltage applied to the operating coil of the regulator causes it to overcome the spring-loaded contact arm. When this condition is reached, the motor-operated rheostat is de-energized and stops, thus maintaining the pre-selected speed as long as the pull of the operating coil of the regulator overcomes the spring-loaded contact arm.

Assuming the electrolytic tinning line to be running at " medium " speed, pressure on the " high " selector push-button will, *via* relays, insert resistance in the potentiometer referred to, which, in turn, will reduce the voltage to the operating coil of the regulator. The spring-loaded contact arm will at once overcome the pull of the operating coil, and so once again energize the motor-operated rheostat *via* the fast armature directional contacts, so increasing the line speed until the pull of the operating coil, supplied from the increase in voltage at the tacho-generator, overcomes the spring-loaded contact arm, thus stopping the motor-operated rheostat.

Normally, to stop the electrolytic tinning line when running in tandem, pressure on the appropriate push-button causes the " slow " armature directional contactor of the motor-operated rheostat to be energized. The rheostat moves towards the " off " position and the speed is reduced under field strengthening to base speed if it was previously running above this value. On reaching minimum generator voltage, the motor-operated rheostat re-sets itself and opens a limit to de-energize all the main contactors for the drive motors, also bringing into operation dynamic braking relays and shunt brakes.

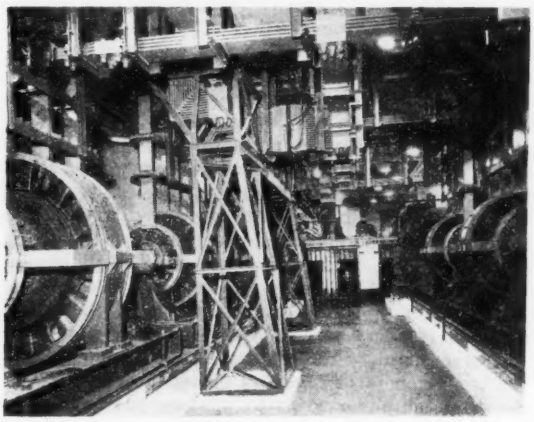


Fig. 13—Plating generators and low-voltage busbars

To stop the line in an emergency, pressure on the emergency-stop push-button energizes the " slow " armature directional contactor for the motor-operated rheostat, and at the same time shorts out the resistance in its armature circuit. This causes the motor-operated rheostat to re-set itself to the " off " position very quickly, reducing the speed of the line quickly, and, in re-setting, brings into operation the dynamic braking and shunt brakes to accelerate the stopping.

Brushes

Various brushes, driven from the A.C. group, are used between the drag bridle and the re-flow equipment. They can be selected to run with, or against, the direction of the strip, by means of selector switches at the main control station. Each drive is equipped with normal starting and protective devices, and a D.C. injection is applied to give rapid stopping, thus preventing scratching of the strip.

The remaining drives in the A.C. group are individually controlled from local push-button stations and employ standard control applications and limiting features. The contactor panels for these drives are mounted on the main A.C. control panel situated in the electrical basement.

Anodic and Cathodic Pickling and Alkaline Cleaning

The anodic and cathodic processes are both electrically assisted. The power in each case is supplied by two generators situated in the electrical basement ; the capacities are 5000 amp. at 12 V., and 2000/1000 amp. at 12/24 V. respectively.

Three selected values of current are supplied by each of the generators, control of which is obtained from the push-button operated relays of the automatic line-speed circuit giving " high," " medium," and " low " values. The shunt fields of the generators are connected to a constant-potential supply from a main exciter, and pressure on the " low " speed push-button of the automatic speed control connects a rheostat in series with each of the generator shunt fields, which provides the means of adjusting the current value desired at that speed.

Depressing either the " high " or " medium " push-buttons will insert alternative rheostats in their respective circuits for a similar purpose. Thus, when selecting any one of the three speed ranges of the electrolytic tinning line, the desired pickling current can be automatically obtained after pre-adjustment of these rheostats.

The alkaline cleaning process is similar to that of anodic and cathodic pickling ; the capacity of the M.G. set in this instance is 5000 amp. at 12 V.

Electroplating

The plating current is supplied from six low-voltage generators installed in the electrical basement immediately below the plating tanks, thereby providing the

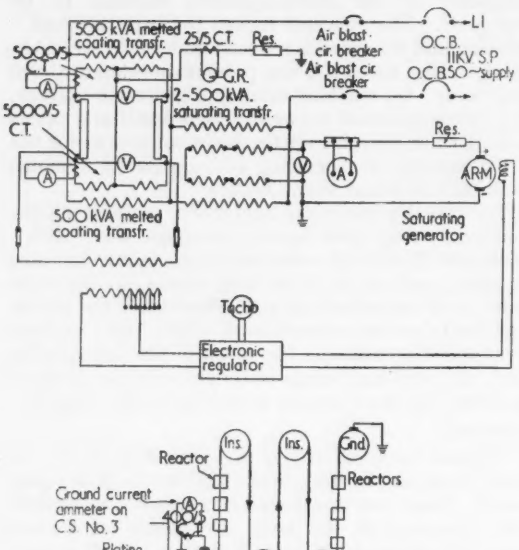


Fig. 14—Diagram of reflow circuit

shortest possible route for the connections between the low-voltage generators and the terminals of the plating tanks.

The interconnections were made in rectangular hard-drawn copper throughout, so designed to give a maximum current density not exceeding 500 amp./sq. in. in any one conductor.

Figure 12 shows the diagrammatic arrangement of the plating circuit, and Fig. 13 shows a view between the low-voltage generators looking towards the A.C. control panel. In this photograph can be seen the 50,000-amp. shunt for measuring the current in the negative busbar forming the common return; also visible is a section of the busbar installation.

The shunt fields of the plating generators are fed from a common exciter of 50 kW., the voltage of which can be varied manually or automatically as the line speed varies.

With manual control the field of the exciter is supplied from a motor-operated potentiometer, movement of which is varied by the operation of a master switch at the main control station, but the circuit is so designed that stopping the electrolytic tinning line will automatically return the motor-operated potentiometer and so reduce the plating current as the speed of the strip reduces. At the moment when the motor-operated potentiometer returns to the "off" position, an auxiliary field on the exciter is momentarily injected to give a 10% buck voltage, thereby "killing" any residual field in the plating generators and eliminating any plating which might have occurred with the strip at rest.

With automatic control the shunt field of the plating generator exciter is fed from an electronic amplifier, the output of which varies as the difference of two voltages; one from a tacho-generator which gives an output voltage proportional to the speed of the electrolytic tinning line, and the other from the voltage drop across the 50,000-amp. shunt carrying the total plating current. Any difference between the two voltages operates a mirror galvanometer, and the mirror, in swinging, excites the photo-electric cells, the output of which controls the grids of two thyraton valves connected to give a full-wave rectified current to the shunt field of the exciter.

As the speed of the line increases from rest, the voltage of the tacho-generator will be greater than the voltage drop across the 50,000-amp. shunt, causing the mirror galvanometer to excite a photo-electric cell to increase the exciter voltage until the difference in voltage between the tacho-generator and voltage drop across the 50,000-amp. shunt is zero, by which time the mirror galvanometer has returned to its neutral position and the plating current is held at a steady value.

As the speed of the line decreases, the voltage drop across the 50,000-amp. shunt will be greater than the voltage at the tacho-generator and the mirror galvanometer will swing the opposite way, the light source energizing a second photo-electric cell to decrease the exciter shunt field to zero.

When the line is running in tandem the speed will be reduced by Ward-Leonard control, and the plating current will decrease in proportion under the influence of the electronic device already described. The 10% voltage buck to the auxiliary field of the exciter to kill any residual in the plating generators is again provided.

Melted-Coating Control

The major equipment for flow-melting the electro-deposited tin on the strip consists of two 500-kVA., 11,000/120-V., single-phase, strip-heating transformers connected in parallel, and two 500-kVA., 11,000/2200-V., single-phase transformers operating as saturable reactors, having their secondaries connected to a 30-V., 300-amp., D.C. generator. Figure 14 shows diagrammatically the arrangement of the heating circuit for automatic control, the current varying with the speed of the line.

As can be seen from Fig. 14, the strip takes the current from specially designed water-cooled conductor rolls fitted with slip rings to which are connected the cables from the heating transformers. One of each is positioned on either side of the muffle tower and immediately above the conductor rolls.

The automatic control of the melted-coating current is dependent upon the output of a differentially wound tacho-generator driven from the drive bridle and a feed-back transformer which is energized from the voltage across the conductor rolls. These two voltages, one being related to the speed of the line, and the other the current flowing through the strip, are fed into an electronic amplifier. The difference between the two voltages varies the bias in the amplifying circuit to control the shunt field of the 30-V. saturating generator.

As the speed of the line increases, the voltage of the tacho-generator rises and biases the valve in the electronic amplifier so as to increase the excitation to the shunt field of the saturating generator, so causing direct current to flow through the secondary

windings of the reactor. This D.C. injection reduces the voltage drop across the primary windings of the reactors and consequently increases the voltage across the primary windings of the heating transformers with a resultant increased voltage at the conductor rolls and current through the strip. With the increase in voltage at the conductor rolls the feed-back transformer voltage will in turn increase to balance the tacho-generator voltage so as to maintain the new value of the heating current.

With normal stopping of the line the strip-heating current will, by the reverse of the automatic features explained, decrease with the speed, until, with the strip at rest, the D.C. saturating current is reduced to zero. To " kill " any residual in the saturating generator, the shunt field is momentarily reversed. This leaves a condition with maximum drop across the saturating reactors and the minimum of heating current in the strip. If the line is not restarted within a predetermined period, the 11-kV. supply to the primary windings of the heating transformers and saturable reactors is interrupted.

For manual control the shunt field of the 30-V. saturating generator is fed from a constant potential supply. Selection of " high," " medium," or " low " running speed causes a relay to insert a rheostat in series with the shunt field to enable the excitation of the saturating generator to be varied and so, in turn, to vary the value of the heating current in the strip.

Muffle Furnace

The muffle furnace, through which the strip passes during the conduction heating process, has an input of 45 kW. at 240 V. and is made up of a number of strip resistance elements. The furnace is lagged with a heat insulator to prevent losses and so avoid non-uniform heating across the width of the steel strip during its passage through the furnace. An automatic potentiometer-type controller, in conjunction with a thermocouple, regulates the temperature of the walls of the furnace at a value below the melting point of tin.

Drag Magnets

Drag magnets are mounted immediately after the looper pit to provide initial drag before the drag bridle and under the belts of the conveyors, the object in this instance being to control the cut sheets in their overlapping, so making the piling operation more positive at high speeds.

Pinhole Detection

The automatic rejection of sheets that are found to have holes in them is effected by the aid of pinhole detectors, one being installed before and one after the processing zone. The detection of pinholes is accomplished by a row of photo-electric cells mounted under the strip, and a row of light sources synchronized in similar positions above the strip. If a hole appears between the photo-cell and the light source, the photo-electric cell is excited to become conducting, thus applying a signal to the electronic amplifier. The amplified signal, in turn, energizes a pin-wheel timer, where the action of a solenoid forces out a pin on the side of the pin-wheel, which, in travelling circumferentially, will close a micro switch. The closing of the micro switch initiates a circuit to energize an off-weight gate solenoid at the piler end of the line. The time taken for the projected pin to close the micro switch is synchronized with the linear speed of the strip, *i.e.*, when the micro switch closes, the sheet with the hole in it has reached the off-weight gate and is rejected.

Off-Weight Gauge

The off-weight gauge causes the sheet to be deflected in a similar manner to the pinhole detector, except that the signal is initiated from a flying micrometer.

Sheet Counters

For counting the sheets, the gap between them, as they pass along the conveyor system, is used to excite a photo-cell. The output from this cell controls the grid of a thyratron, this valve in turn operating the coils of the mechanical counters.

Public Address System

A public address system operating from a three-stage, high-gain amplifier provides intercommunication between the main control station, the control stations at the entry and finishing ends, the electrical basement, and the mechanical basement. Standard equipment is employed to provide two-way speech.

High-Tension Circuits

The feeder cable from the site sub-station to the melted - coating - unit 500 - kVA. transformers and reactor is a 0·06-sq. in. 3-core, P.I.L.C.D.W.A.S. cable ; one core is dummied, run on open cleats in a cable tunnel specially provided for the various feeders to the electrical basement. Controlling the 11-kV. supply to the melted-coating unit is a double-pole air-blast circuit-breaker positioned in the electrical basement and remote-controlled from the main control station. To safeguard against effects arising from switching on and off the melted-coating unit, divertors have been fitted across the E.H.T. line connection of the heating transformer so as to by-pass any voltage surges to earth. Choice of an air-blast circuit-breaker was made principally on mechanical considerations and the necessity of reducing to a minimum the fire hazard in the electrical basement. The interconnection between the air-blast circuit-breaker and the heating transformers and reactors is a 0·1-sq. in., 3-core, 11-kV. T.R.S. single-wire, armoured ozone-proof cable (one core used for paralleling). This class of cable was chosen because of a design difficulty in adapting trifurcating boxes for a P.I.L.C.D.W.A.S. cable. Terminal boxes with conduit entries were supplied with the transformer and reactors, and it has since been learned that U.S.A. practice was to use V.I.R. 11-kV. cables run in conduit.

Low-Tension Circuits

The 440-V. feeders to the main A.C. control panel are in duplicate, each feeder consisting of three 1-sq. in. P.I.L.C.S. cables per phase, run in trefoil formation on cleats, and terminating in a two-circuit selector

cubicle. From this cubicle a single feeder, of similar section per phase, connects to the incoming panel on the main A.C. control panel. All major circuits controlled from the main A.C. control panel are protected with air-circuit breakers, the operation of which is local only, and not remote from the various control stations.

As previously explained, the 250-V. D.C. supply for the constant-potential group is taken from the cold-mill service switchboard, and the feeder to the main D.C. control panel consists of two 1-sq. in. single-core 660-V. P.I.L.C.D.W.A.S. cables per pole, run direct to the electrical basement.

The outgoing circuits from the main A.C. and D.C. control panels to the control stations, motors, and ancillary equipment, are, for the major part, carried out in flexible stranded, single and multi-cored, special tough rubber-sheathed cable run in conduits, affixed either in concrete or in nests suspended from the ceiling or walls. So multitudinous are the small power and control circuits that the conduit system is arranged to contain each circuit group in its individual conduit. This method, though complicated in erection and more costly than common trunking, trays, or cleats, affords advantages for maintenance requirements not available with the other less costly methods of wiring.

Low-Voltage Circuits

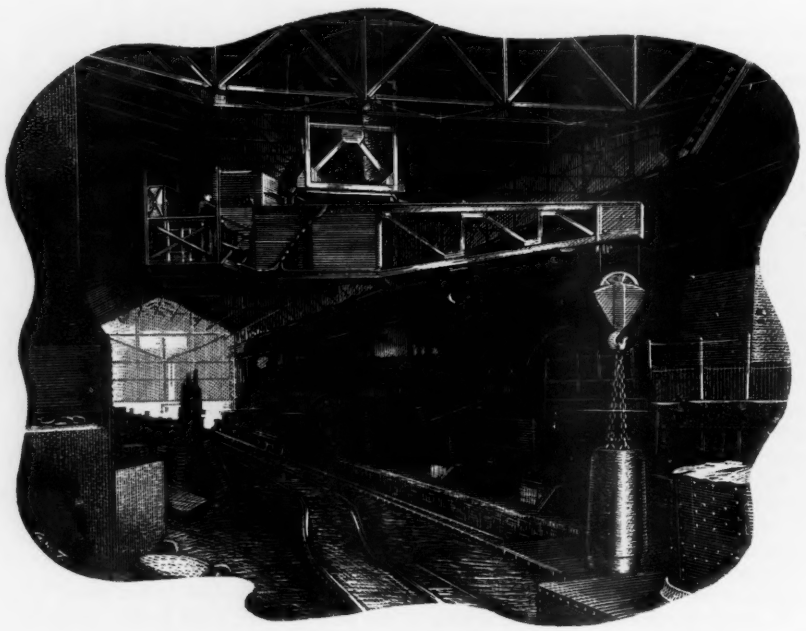
The connections between the low-voltage generators supplying current to the pickling and plating units are carried out in rectangular-section copper bar, the busbar installation being so designed as to limit the current density in any one conductor to a maximum of 500 amp./sq. in.

The pickling and plating generators are positioned in the electrical basement immediately beneath their respective units, the connections to which have been taken through special sealing glands in the concrete floor. Some idea of the busbar installation, for the plating unit in particular, can be gained from the make-up of the common return which comprises twelve sections of $8 \times \frac{1}{2}$-in. rectangular copper section, each section being spaced $\frac{1}{2}$ in. apart. To this common-return conductor (negative), in the centre position for equal current loading of the busbar, is connected the 50,000-amp. shunt for measuring the total current and supplying a reference voltage to the electronic amplifier for automatic control of the plating-generator voltage.

Connections to the anodes from the basement uprisers are by means of flexible laminated copper straps, thus enabling the anodes to be adjusted without removing any of the heavy copper sections.

The conductor rolls described elsewhere in this paper are fitted with slip rings at either end. The current passing from the strip completes its circuit to the generators *via* the slip rings, its brushes, the uprisers, and the common negative busbar in the electrical basement.

Connections to the pickling and cleaning units are similarly arranged.



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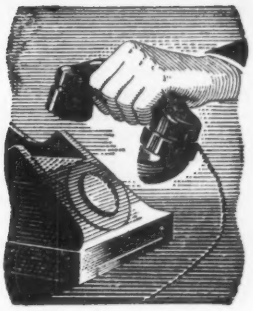


ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Andrew Carnegie Research Fund

Research Grants and Travelling Scholarships

Andrew Carnegie Research Grants and Travelling Scholarships are awarded to suitable applicants to enable them to conduct researches into the metallurgy of iron and steel. The amount of any one research grant will not exceed £250 in a year and the normal range is £50 to £200. The grants are tenable within the United Kingdom. The value of the travelling scholarships will depend upon the circumstances of each case, but will normally be of the order of £500 although smaller or substantially greater sums may be given. The scholarships will usually be tenable for one year and are intended to assist recipients to conduct researches outside the United Kingdom.

Conditions

A condition of the awards is that candidates must be under 35 years of age. There is no restriction on sex or nationality. The results of the research are to be communicated to The Iron and Steel Institute in the form of a report for publication. An Andrew Carnegie Gold or Silver Medal may be awarded to the author of the report which, in the opinion of the Council, is the most meritorious of the year.

Grants are normally paid in four quarterly instalments: the first on award, the second and third on receipt of satisfactory brief progress reports, and the final instalment on receipt of the completed report.

Sir Henry Bessemer

Fifty years ago the death occurred at his home at Denmark Hill, London, of Sir Henry Bessemer. He was eighty-five. By his death British metallurgy had to deplore the loss of one whose name would be forever associated with the record of its progress and development. His discovery of the means of rapidly and cheaply converting pig iron into steel by blowing a blast of air through the molten iron was the result of labours and experiments that extended over a period of more than ten years, the results being obtained only after many disheartening failures.

The son of Anthony Bessemer, a typefounder and inventor of numerous mechanical contrivances, and a Member of the French Academy of Sciences, Henry Bessemer was born on 18th January, 1813, at Charlton, in Hertfordshire.

He was one of the founders of The Iron and Steel Institute, and in 1870 he succeeded the Duke of Devonshire and was elected its second President. In 1885 he became Trustee of the Institute's invested funds. He presented to the Institute his collection of early specimens of Bessemer steel, dating back to 1856, and in 1873 he instituted the Bessemer Gold Medal, which is awarded annually by the Institute for conspicuous merit in connection with iron and steel manufacture.

A verbatim copy of the paper by means of which the Bessemer process was first made known to the world will be found in the *Journal of The Iron and Steel Institute*, 1898, No. I, p. 305. Entitled "*On the Manufacture of Iron and Steel without Fuel*," it was read before the British Association for the Advancement of Science, at Cheltenham, on 13th August, 1856, and published in full in *The Times* on the following day.

Seventy-Five Years Ago

The first foreign meeting of The Iron and Steel Institute was held in the summer of 1873, in the city of Liége. The event was one of some importance to the citizens, for on the day of arrival of the members, Monday, 18th August, the city, set in the midst of a flourishing iron industry, was *en fête*. For at least half-a-mile before reaching the station, the Belgian Reception Committee had arranged that their intended guests should be saluted by volleys of artillery. As the train drew into the station the band of the 12th Regiment struck up "God save the Queen," and afterwards the band of the City Fire Brigade played the Belgian National Anthem. The station itself was decorated with evergreens and banners and was crowded with Belgian engineers, ironmasters, and others composing the Reception Committee.

The Committee had taken great care with the arrangements for the meeting: apart from the official business of reading papers there were many social functions and excursions. At the official reception the visitors were welcomed by the Burgomaster, aldermen, and councillors, and after speeches by the Burgomaster, the President (Sir Lowthian Bell), and others, the "Wine of Welcome" was handed to each member. In the evening there was a grand fête and a concert in the Boverie Gardens.

The following day, after papers had been presented, during various excursions by steamboat members visited numerous works on the banks of the river Meuse. In the evening there was another grand fête in the Place du Théâtre, the like of which, the local papers reported, was never before witnessed in Liége. The square was illuminated by myriads of coloured lamps and at intervals the whole square was lighted by magnesium flares displayed from the roof of the theatre. On a large platform in front of the theatre 500 performers, mostly workmen from neighbouring iron or coal works, gave a concert.

Following a session for the presentation of papers, on Wednesday morning, the members were taken by special steamboat to visit the works of John Cokerill and Co., at Seraing. With the exception of the Essen Works this establishment was then the largest individual works in the world. In the evening the great event of the week devoted to pleasure took place at the Salle de Renomée. This was the banquet given by the Reception Committee to their guests. In addition to the members of the Institute there were present 450 Belgians and representatives of the French, German, and American iron trades. Special attractions and souvenirs of the banquet were the elaborate menus—cards two feet long by sixteen inches wide—and small medals which had been struck for the occasion.

On Thursday, after the final session of technical discussions, members were taken to the palace at Laeken to be received by His Majesty King Leopold II. A small party of members dined for two hours with the King, and later some 300 members and their hosts were presented.

Before embarking for home on Friday members were given the opportunity of visiting the coal works and mines of M. d'Adrimont at the Hazard, Micheroux.

NEWS OF MEMBERS

Birthday Honours

▶ The President and Members of Council offer their congratulations to the following Members whose names appeared in the Birthday Honours List.

▶ Mr. R. CRICHTON, Chairman of the West Cumberland Industrial Development Co., Ltd., has been made a Knight Bachelor.

▶ Mr. JOB HOLLAND has been awarded the O.B.E. for his services to the refractories industries.

▶ Mr. D. W. SMITH, Chislehurst, Kent, has been awarded the M.B.E.

Recent Appointments

▶ Mr. E. HUGH ARMITAGE, Chairman of Messrs. Brown, Bayley's Steel Works, Ltd., has resigned from the Board. Mr. S. GUY NEWTON and Mr. HARRY BULL become Joint Managing Directors of the Company.

▶ Mr. W. E. BALLARD has been elected President of the Birmingham Metallurgical Society.

▶ Mr. J. LLOYD BENTLEY has been appointed manager of " Wilson's " Forge (1929), Ltd., Bishop Auckland.

▶ Mr. A. C. BREARLEY is now chief metallurgist to K. and L. Steelfounders and Engineers, Ltd., Letchworth, Herts.

▶ Mr. D. W. BROOKER is now engaged in research work on metal-to-rubber bonding, with Metalastik, Ltd.

▶ Mr. DANIEL CLARK, chief metallurgist of the Commonwealth Steel Company, has been elected President of the Australian Institute of Metals.

▶ Mr. H. R. CURNICK is now with the Union Steel Corporation (South Africa), Ltd., Vereeniging, Transvaal.

▶ Mr. N. DEAN has sailed for South Africa to take up an appointment as assistant blast-furnace superintendent at the South African Iron and Steel Industrial Corporation, Ltd., Pretoria, Transvaal.

▶ Dr. HUGH FORD has been appointed Reader in Applied Mechanics at London University and an Assistant Professor of Mechanics at the City and Guilds College, Imperial College of Science and Technology.

▶ Mr. G. F. GILLOTT has recently been appointed superintendent of the Metal and Steel Factory, Ishapore. He was previously at the Ordnance Factory, Ambarnath, Bombay.

▶ Dr. W. N. HINDLEY, after 24 years on the scientific staff of the Armament Research Department, Woolwich, is joining the metallurgical staff of the Director of Weapon Research (Defence), Shell Mex House, London, W.C.2.

▶ Mr. V. S. KINGSWOOD has left the Morgan Crucible Co., Ltd., to join the staff of Battersea Polytechnic as a lecturer in metallurgy.

▶ Mr. D. C. F. LUNN, who recently resigned from the staff of Philips Electrical, Ltd., has taken up an appointment with the De Havilland Aircraft Co., Ltd., at Stag Lane, Edgware, Middlesex.

▶ Mr. J. B. MCINTYRE has been appointed senior lecturer in metallurgy at the National Foundry College, Wolverhampton.

▶ Mr. E. MENSFORTH has been elected a Director of Messrs. John Brown and Co., Ltd.

▶ Mr. S. G. NEWTON has become Chairman of the Hoffman Manufacturing Co., Ltd., on the resignation of Mr. J. W. Garton, who becomes Managing Director.

▶ Mr. F. PICKWORTH has been appointed Chairman, and Mr. R. G. H. TAYLOR, Managing Director, of Messrs. Taylor Bros. and Co., Ltd.

▶ Mr. R. L. RICHARDS has left the Standards Association of Australia to take up a position as technical assistant with the British Standards Institution.

▶ Dr. M. TCHORABJI SIMNAD is leaving the University Chemical Laboratory, Cambridge, to go to the United States of America, as a result of an award of the Weston Research Fellowship of the American Electrochemical Society. Dr. Simnad has been working at Cambridge on corrosion problems with Dr. U. R. Evans.

▶ Mr. T. H. SUMMERSON has been nominated to serve on the Northern Area Committee of the British Electricity Authority.

▶ Mr. B. THORNTON has been appointed Joint Managing Director, with Mr. C. J. Barker, of The Wellman Smith Owen Engineering Corporation, Ltd., in succession to the late Mr. Sydney Smith.

▶ Mr. JAMES TENNENT, J.P., D.L., Hon. Sheriff, has been appointed Chairman of Messrs. R. B. Tennent, Ltd., Coatbridge. Mr. Tennent, who will continue to act as Managing Director, was for five years Provost of Coatbridge and is a Deputy Lieutenant of the County of Lanark. He is a Past President of the West of Scotland Iron and Steel Institute and has been Chairman of the British Roll Makers Association. He also holds the position of Deputy Chairman and Joint Managing Director of the British Rollmakers Corporation, Ltd., Wolverhampton.

▶ Mr. D. J. TONKS is now working with the British Iron and Steel Research Association at the Metal Flow Research Laboratory, 41, Doncaster Street, Sheffield.

▶ Mr. PETER WRIGHTSON, O.B.E., second son of the Chairman, Sir T. G. Wrightson, Bt., has been appointed a Director of Messrs. Head, Wrightson and Co., Ltd., Thornaby-on-Tees. He succeeds Mr. W. I. Wrightson, who retired from the Board last year.

Memoranda

▶ Mr. E. L. DIAMOND, Head of the Mechanical Section of the Plant Engineering Division of the British Iron and Steel Research Association, has been transferred from Associate Membership to full Membership of the Institution of Mechanical Engineers. It is regretted that Mr. Diamond was referred to as Mr. H. L. Diamond in the biographical note on page 79 of the May, 1948, issue of the *Journal*.

▶ Mr. S. E. GRAEFF, of Messrs. Richard Thomas and

Baldwins, Ltd., has changed his address to: The Steel Company of Wales, Ltd., P.O. Box No. 9, Port Talbot.

▸ Mr. A. C. HARRIS has now returned to Great Britain, having left the Steel Corporation of Bengal, India, in March of this year.

▸ Sir ANDREW MCCANCE, F.R.S., President of the Institute, has been awarded the honorary degree of LL.D. of Glasgow University.

▸ Mr. F. WOODIFIELD, Director and Works Manager of the Park Gate Iron and Steel Co., Ltd., Rotherham, and President of the Iron and Steel Trades Employers' Association, is to attend the International Labour Conference at San Francisco as one of the advisers appointed by the British Employers' Federation.

Obituary

The Council regret to record the deaths of:

Monsieur H. E. C. FAUCILLON, Schneider et Cie., Paris, on 13th March, 1948, aged 64.

Mr. JOHN HENRY MOYSEY, of Pinner, Middlesex, on 19th May, 1948.

Sir HENRY ROBERTSON, Chairman of the Brymbo Steel Co., Ltd., the Broughton and Plas Power Coal Co., Ltd., and the Minera Lime Co., Ltd., aged 86.

Mr. SYDNEY SMITH, Managing Director of the Wellman Smith Owen Engineering Corporation, Ltd., on 30th May, 1948.

CONTRIBUTORS TO THE JOURNAL

J. L. Harrison, F.I.M.—Steelplant manager at Messrs. Catton and Co., Ltd., Leeds. Mr. Harrison was educated at the Grammar School, Brigg, Lincolnshire. In 1927 he joined the staff of the Scunthorpe Works of Messrs. John Brown and Co., Ltd., as technical assistant to the works manager. After the merging of that firm with Messrs. Thos. Firth and Co., Ltd., he took over responsibility for the electric and converter plants, and was later appointed steelplant manager. He took up his present position in January 1946. Mr. Harrison is a member of the Melting Sub-Committee of the Steel Castings Division and of the Pyrometry Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association.

A. Hartley, B.Sc.—A member of the staff of the Steel Castings Division of the British Iron and Steel Research Association. Mr. Hartley received his technical training at Leeds University where he was awarded an honours degree in metallurgy. Subsequently he spent four years on research work for the Alloy Steels Research Committee, on the high-temperature oxidation of metals, and also on the overheating and burning of steel. Mr. Hartley took up his present position in 1947.

W. C. Newell, Ph.D., D.I.C., A.R.C.S., F.R.I.C.—Head of the Steel Castings Division of the British Iron and Steel Research Association. Dr. Newell was born in London in 1913, and after a public school education entered the Royal College of Science, where he graduated with honours in chemistry. He then served for two years as a part-time demonstrator at the same College whilst conducting physico-chemical research under the direction of Dr. H. J. T. Ellingham. Between 1936 and 1945 Dr. Newell was employed at the Brown-Firth Research Laboratories, where he was responsible for developments in steelmaking and non-ferrous alloy manufacture. In the more academic field, Dr. Newell has continued to apply his early skill in high-vacuum technique, and has given a number of papers before the Royal Society and The Iron and Steel Institute upon oxygen, hydrogen, and nitrogen and their association with steel.

R. J. Love—A research engineer at the Motor Industry Research Association, Brentford, Middlesex. Born at Portsmouth in 1921, Mr. Love served a five-year apprenticeship at H.M. Dockyard, Portsmouth, and during this time received his technical education at H.M. Dockyard School. He was awarded a Whitworth Scholarship in 1940, and studied at King's College, University of London, until 1942, where he obtained the King's College diploma in mechanical engineering. Mr. Love joined the staff of the Motor Industry Research Association (formerly the Institution of Automobile Engineers Research Department) in 1943 and since that date he has been engaged in research on the fatigue strength of crankshafts.

T. P. Colclough, C.B.E., D.Sc.—Technical advisor to the British Iron and Steel Federation, chief technical advisor to the Control Commission for Germany (metallurgy branch), and consultant to the Iron and Steel Board, Ministry of Supply. Dr. Colclough was awarded the degree of M.Sc. at Manchester in 1906, and graduated in metallurgy at Sheffield, where he was awarded the Mappin Medal in 1920. The degree of D.Sc. of Manchester University was awarded to him in 1937. He began his career in the steel industry on becoming chief chemist of the Brown-Firth Research Laboratories in 1916. In 1920 he went to the Park Gate Iron and Steel Co., Ltd., and during the course of nine years he held the positions of chief chemist, open-hearth manager, and chief metallurgist. His next appointment was as

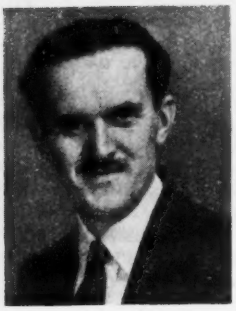
W. C. Newell

J. L. Harrison

T. P. Colclough

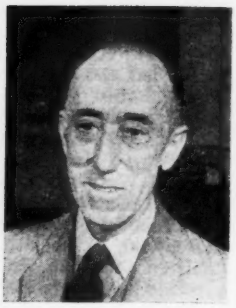
R. J. Love

J. Dearden



D. Joyce

L. Reeve



A. Bridge

Technical Director to Messrs. H. A. Brassert and Co., Ltd., a position which he held until 1942. He was also technical advisor to the Hermann Göering Works in Germany and Austria. During the recent war Dr. Colclough was technical advisor to the Iron and Steel Control, Ministry of Supply, and in 1947 was awarded the C.B.E.

Arthur Bridge—Chief ironworks engineer at the Appleby-Frodingham Steel Company. Mr. Bridge received his technical education at the Warrington Technical Institute and at the Manchester College of Technology. He served his apprenticeship with the Pearson and Knowles Coal and Iron Co., Ltd., with whom he was employed as a draughtsman from 1919 until 1929, when he left to take up a position in the drawing office of the Frodingham Iron and Steel Co., Ltd. In 1936 he was appointed assistant engineer at the Appleby Ironworks and three years later works engineer; this position he held until his present appointment in 1943.

J. Dearden, M.Sc., A.M.I.Mech.E., F.I.M.—Chief metallurgist at the Scientific Research Department, British Railways (London Midland Region). After graduating in metallurgy at Manchester University in 1925, Mr. Dearden entered the Horwich locomotive works of the L.M.S. Railway as an engineering pupil and worked for three years in the various workshops. This period of practical training was followed by seven years as power plant engineer at Horwich and four years as works metallurgist at the St. Rollox (Glasgow) Works of the L.M.S. Railway. After attending the British Foundry School in Birmingham he was transferred to the L.M.S. Research Department, Derby, under Dr. H. O'Neill, where he has carried out research on welding.

L. Reeve, Ph.D., B.Sc., F.I.M.—Chief metallurgist, Appleby-Frodingham Steel Company. Dr. Reeve received his technical education at King's College, London, and at the Imperial College of Science, London, where from 1925 to 1929 he worked with the late Professor W. A. Bone, F.R.S., on the physical chemistry of blast-furnace reactions. In 1929 he joined the newly formed technical department of the British Iron and Steel Federation, and became the first Secretary of its Blast-Furnace Committee. After four years in the U.S.A., with the A. O. Smith Corporation, Milwaukee, Dr. Reeve joined the Appleby-Frodingham Steel Company, and was made chief metallurgist in 1942.

D. Joyce—Blast-furnace manager at the Consett plant of the Consett Iron Co., Ltd. After serving his apprenticeship at the Workington plant of The United Steel Companies, Ltd., Mr. Joyce became blast-furnace assistant at the Redbourn Works, Scunthorpe, of Messrs. Richard Thomas and Co., Ltd., in 1937, and assistant blast-furnace manager in 1940. Two years later he transferred to the Millom blast-furnace plant of the Millom and Askam Hematite Iron Co., Ltd., and held a similar position until 1944 when he was promoted to blast-furnace manager. Mr. Joyce took up his present appointment in 1946.

IRON AND STEEL ENGINEERS GROUP

Eighth Meeting

The Eighth Meeting of the Iron and Steel Engineers Group will be held on Wednesday, 24th November, 1948, at the offices of the Institute, 4, Grosvenor Gardens, London, S.W.1. Three papers on the handling of materials in iron and steel works will be presented and discussed.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Conference on Foundry Core Bonding Agents

The object of a conference to be held at Ashorne Hill, near Leamington, on 21st and 22nd October, 1948, is to bring to the notice of founders the wealth of information that has been obtained in recent years on the new materials that may be used for the bonding of foundry cores. The use of such materials, in many cases with an appreciable reduction in cost, would enable the linseed oil used hitherto to be diverted to alleviate the shortage of edible fats.

The conference will be divided into three sessions:

Session 1—Papers on the natural resources of the materials; on recent work by B.I.S.R.A. on the practical and fundamental aspects of bonding, and on the properties of new materials, such as plastics and petroleum products.

Session 2—Papers on the experience of founders with such materials.

Session 3—Consideration of the impact of these materials on matters such as core blowing, and dielectric and infra-red heating.

INSTITUTE OF METALS

Autumn Meeting at Cambridge, 1948

The Autumn Meeting of the Institute of Metals will be held at Cambridge from Tuesday, 14th September, to Friday, 17th September, 1948. In addition to the technical sessions, a large number of works and other visits have been arranged.

INSTITUTION OF METALLURGISTS

Fourth Annual General Meeting

The Fourth Annual Meeting of the Institution of Metallurgists was held on Thursday, 10th June, 1948, at the Offices of the Institution, 4, Grosvenor Gardens, London, S.W.1, under the Chairmanship first of the retiring President, Dr. J. W. Jenkin, and afterwards of the newly elected President, Dr. Maurice Cook.

The new list of Council and Officers is as follows :

President

MAURICE COOK, D.Sc., Ph.D.

Past-Presidents

HAROLD MOORE, C.B.E., D.Sc., Ph.D., F.R.I.C., F.Inst.P.
J. W. JENKIN, Ph.D., B.Sc., A.R.I.C.

Vice-Presidents

G. L. BAILEY, M.Sc.
E. W. COLBECK, M.A.
R. A. HACKING, O.B.E., M.Sc.
R. MATHER, B.Met.
A. J. MURPHY, M.Sc.
F. C. THOMPSON, D.Met., M.Sc.

Honorary Treasurer

C. J. SMITHELLS, M.C., D.Sc.

Ordinary Members of Council Representing the Fellows

N. P. ALLEN, D.Sc.,M.Met.
W. E. BARDGETT, B.Sc., A.M.I.Mech.E.
L. E. BENSON, M.Sc.
E. GREGORY, Ph.D., M.Sc., F.R.I.C.
W. HUME-ROTHERY, M.A., D.Sc., Ph.D., F.R.S.
J. E. HURST, D.Met.
N. P. INGLIS, Ph.D., M.I.Mech.E.
L. B. PFEIL, O.B.E., D.Sc., A.R.S.M.
W. W. STEVENSON, A.Met., F.R.I.C.

Ordinary Members of Council Representing the Associates

W. E. BALLARD, F.R.I.C.
R. GRIFFITHS, M.Sc.
L. ROTHERHAM, M.Sc., A.Inst.P.
C. E. HOMER, Ph.D.
W. K. B. MARSHALL, B.Eng.
Professor H. O'NEILL, D.Sc., M.Met.

Nominated by The Iron and Steel Institute

H. H. BURTON
J. SINCLAIR KERR

Nominated by the Institute of Metals

Col. P. G. J. GUETERBOCK, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A., A.D.C.
Sir ARTHUR SMOUT, J.P., A.R.I.C., M.I.M.M.

Registrar-Secretary

ARTHUR D. MERRIMAN, G.C., O.B.E., M.A., M.Ed., D.Sc., C.I.Mech.E.

NEWS OF SCIENCE AND INDUSTRY

Birthday Honours

Honours have been conferred on the following who are well known in the iron and steel industry :

Mr. ELLIS HUNTER, Deputy Chairman and Managing Director of Messrs. Dorman, Long and Co., Ltd., and President of the British Iron and Steel Federation, has been made a Knight Bachelor.

Mr. H. E. G. WEST, Managing Director of the Newton Chambers Companies, has been made a Knight Bachelor.

Mr. H. W. CREMER, President of the Institution of Chemical Engineers, has been awarded the C.B.E.

Lt.-Col. W. FRENCH, Superintendent of the Technological Department of the City and Guilds of London Institute, has been awarded the C.B.E.

Dr. W. F. HIGGINS, Superintendent of the Physics Division, National Physical Laboratory, has been awarded the C.B.E.

Dr. W. R. JONES, Professor Emeritus of the University of London and the Imperial College of Science and Technology, has been awarded the C.B.E. for his services to the Board of Trade.

Dr. W. T. K. BRAUNHOLTZ, Secretary of the Institution of Gas Engineers, has been awarded the O.B.E.

Mr. S. T. CLARK, production and supply officer of the British Iron and Steel Federation, has been awarded the O.B.E.

Liverpool Metallurgical Society

At an initial meeting in Liverpool approximately 120 people expressed their intention of joining the proposed Liverpool Metallurgical Society. A Committee has been formed and it has been decided not to hold another meeting before the autumn, but to concentrate on the preparation of a syllabus for the 1948–49 session. The Committee proposes to arrange six lectures at monthy intervals, commencing in October, to include joint meetings with the Liverpool Engineering Society and the North-West Section of the Society of Chemical Industry. An Annual General Meeting is proposed for April 1949. All interested, who have not already made contact, should communicate with Mr. C. W. J. Gellatley, 7, Woolacombe Road, Liverpool, 16, and assist in making this a really live organization.

British Association for the Advancement of Science

A Meeting of the British Association for the Advancement of Science will be held at Brighton from 8th to 15th September, 1948. The subjects to be discussed include : Achievements of X-ray analysis, newer metals and alloys in industry, the metric system, and the selection of university students. The week's activities also include excursions, dinners, garden parties, films, and exhibitions. Full particulars may be obtained from the Secretary, British Association, Burlington House, London, W.1.

National Association of Iron and Steel Stockholders

The Twentieth Annual General Meeting of the National Association of Iron and Steel Stockholders was held on 8th June, 1948, at Ashorne Hill, near Leamington Spa, Warwickshire. Reports were presented on the work of the Association during the past twelve months, and a wide range of subjects was covered ; particular attention was paid to the past and future supply position, and the efforts which are being made to render assistance to the authorities.

The Officers re-elected were Mr. Ernest B. Hall (President), Mr. M. C. Wade, M.C., J.P. (Vice-Chairman), and Mr. Geo. A. Tawse (Honorary Treasurer). The other Officers of the Association are Mr. S. H. Gillett, M.C., F.C.A. (Independent Chairman), and Mr. W. Spencer Woodcock (Secretary).

German Steel-Industry Commission

A Commisson has been set up to study the German steel industry and to make recommendations for increasing its output. The commission consists of two British members (Mr. J. Sinclair Kerr, Chairman, and Mr. H. C. Dawson), two from the United States, and two German members.

Joint Conference on Liquid Fuels

A Joint Conference on "*Modern Applications of Liquid Fuels*," organized by the Institute of Petroleum and the Institute of Fuel, will take place at Birmingham University from 21st to 23rd September, 1948. The object of the Conference is to place the technical considerations involved in utilization of liquid fuels, at this time, before the fuel-using public, indicating the proper place of alternative fuels in various circumstances. The Conference President is Mr. J. A. Oriel, C.B.E., M.C., and the provisional programme is as follows:

Tuesday, 21st September, 1948

11.30 A.M. to 12.30 P.M.—Opening session: Address by the President, entitled "*The Place of Liquid Fuel in the British Economy.*"

2.0 P.M. to 4.30 P.M.—Afternoon session: "*Fuel Oil in the Steel Industry.*"

7.15 P.M. to 9.0 P.M.—Evening session: Lecture on "*Domestic Heating.*"

Wednesday, 22nd September, 1948

10.0 A.M. to 12.30 P.M.—Morning session: "*Fuel Oil in the Metal Industries.*"

2.0 P.M. to 4.30 P.M.—Afternoon session: "*Fuel Oil in the Glass and Ceramic Industries.*"

Evening: Social Function.

Thursday, 23rd September, 1948

10 A.M. to 12.30 P.M.—Morning session in parallel: "*Gas Turbines for Land and Marine Power Purposes*," or "*Agricultural Drying Processes.*"

2.0 P.M. to 4.30 P.M.—Afternoon session in parallel: "*Diesel Engines for Power Generation and Railway Traction*," or "*Oil for Gas Making.*"

An exhibition of items related to the subjects of the various sessions is being arranged. Further details of the Conference and forms of application for membership may be obtained from the General Secretary, Mr. R. W. Reynolds-Davies, 18, Devonshire Street, London, W.1.

Exchange of Students for Technical Experience

The Governing Body of the Imperial College of Science and Technology has decided that the schemes for the international exchange of students during summer vacations, initiated by their Vacation Work Committee in 1946, shall be broadened in 1949 to include university students from other colleges in Great Britain.

The exchange is operated through the recently established International Association for the Exchange of Students for Technical Experience, which at present includes Belgium, Czechoslovakia, Denmark, Finland, France, the Netherlands, Norway, Sweden, and Switzerland.

Memoranda

ARMCO, LTD.—The London office of Armco, Ltd., is now at 75, Grosvenor Street, W.1 (telephone Mayfair 4756) Correspondence should not be addressed to their Letchworth Works.

BRITISH COAL UTILISATION RESEARCH ASSOCIATION—The offices of the British Coal Utilisation Research Association are now at their new research station at Randall Road, Leatherhead, Surrey (telephone Leatherhead 4411, telegraphs "Curassoc," Leatherhead). The London office, to which enquiries relating to industrial liaison service should be addressed, will be maintained at 13, Grosvenor Gardens, S.W.1.

BRITISH OVERSEAS ENGINEERING AND CONSTRUCTION, LTD., announce that in future all communications should be addressed to 28, Eccleston Street, London, S.W.1 (telephone Sloane 0071–3).

INSTITUTION OF PRODUCTION ENGINEERS—The headquarters of the Institution of Production Engineers have now been reoccupied and all communications should be addressed to the Institution at 36, Portman Square, London, W.1 (telephone Welbeck 6813–7).

INSTITUTION OF WORKS MANAGERS—The Institution of Factory Managers and the Institution of Works Managers amalgamated on 1st July, 1948, under the name of the Institution of Works Managers. The registered office of the Institution is at 67–68, Chandos Place, London, W.C.2.

MANCHESTER ASSOCIATION OF ENGINEERS—As from 1st July, 1948, Mr. G. M. P. McKellen will be Secretary of the Manchester Association of Engineers and the new address of the Association will be 20, Booth Street, Manchester, 2.

Mr. P. WARDROBE has been elected President of the Crucible Steel Makers Association in succession to Mr. P. B. Henshaw.

DIARY

26th Aug.–11th Sept.—1948 Machine-Tool and Engineering Exhibition—Olympia, London.

1st–4th Sept.—SOCIETY OF GERMAN CHEMISTS IN THE BRITISH ZONE—Annual Meeting in Hanover.

4th–20th Sept.—International Exhibition of Pure and Applied Chemistry—Charleroi, Belgium.

12th–19th Sept.—21st Congress of Industrial Chemistry—Organized by the Société de Chimie Industrielle de Paris and the Federation des Industriels Chimiques de Belgique—Brussels. Particulars from Société de Chimie Industrielle, 28, Rue St. Dominique, Paris, VII.

14th–17th Sept. — INSTITUTE OF METALS — Annual Autumn Meeting at Cambridge.

TRANSLATION SERVICE

(The previous announcement was made in the June, 1948, issue of the *Journal*, p. 208.)

TRANSLATIONS AVAILABLE

No. 347 (German). F. BLEILÖB: "Equations for the Time–Elongation Curves in Creep Tests." (*Archiv für das Eisenhüttenwesen*, 1940, vol. 13, pp. 489–496).

No. 348 (German). W. BADING: "The Development of Basic Converter Practice." (*Stahl und Eisen*, 1947, vol. 66–67, Apr. 24, pp. 137–149; May 22, pp. 180–186; June 19, pp. 212–223).

No. 349 (German). Discussion on the paper by E. HOUDREMONT and G. BANDEL: "The Effect of Titanium on the Creep Strength of Steels." (*Archiv für das Eisenhüttenwesen*, 1942, vol. 16, Sept., pp. 97–100).

TRANSLATIONS IN COURSE OF PREPARATION

(German). B. MATUSCHKA: "The Heat Equilibrium Between Ingot and Ingot-Mould Wall." (*Archiv für das Eisenhüttenwesen*, 1929, vol. 2, June, pp. 405–411).

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

Increase of Charges

Members are reminded that, as from 1st July, 1948, the price of translations has been increased to £1 for one copy of any translation in the Series, and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance.

Translations in the Series are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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ORES—MINING AND TREATMENT

Mechanization Developments in the Iron Mines of Eastern France. P. Dosmond. (Revue de l'Industrie Minérale, 1948, Apr., pp. 244–266). Progress made in the mechanization of the iron mines of Eastern France is discussed.—R. F. F.

Reduction of the Variability of Magnitogorsk Ores. N. L. Goldshtein. (Stal, 1948, No. 3, pp. 210–214). [In Russian]. Changes in mining practice and ore stock-yard organization to deal with the increasing variability in ore composition which has resulted from the exploitation of deeper deposits at Magnitogorsk, are considered.—S. K.

The Heavy-Medium Processes. F. Fleischer. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Jan.–Mar., pp. 17–23). A number of heavy-medium processes for separating minerals, including the du Pont, S.-J (Sophia-Jakoba), Lessing, Tromp, and Chance methods are critically examined.—R. A. R.

Iron Mines of Ontario. W. M. Bonham. (Canadian Mining Journal, 1948, vol. 69, Mar., pp. 75–78). The present production of iron ore and sinter at the mines in the Michipicoten range and at Steep Rock Lake, Ontario, are reviewed with notes on the reserves and commercial prospects.—R. A. R.

Beneficiation of Magnetite Ore. A. P. Kvaskov. (Stal, 1948, No. 3, pp. 206–210). [In Russian]. A description is given of experiments on the beneficiation of magnetite ores from various locations in the U.S.S.R., flow-sheets of the processes used being given.—S. K.

Some Modern Apparatus for Ore Treatment. (Echo des Mines, 1948, Mar., pp. 51–52). Some modern sizing, washing and separating plant for ore treatment is briefly described.—R. F. F.

FUEL—PREPARATION, PROPERTIES, AND USES

The Technical Possibilities of Fuel Economy in the Melting of Metals, and in Particular, Iron in the Cupola. J. Bobst. (Fonderie, 1946, Special Issue, pp. 472–475). The author reviews generally factors that may result in increased fuel economy in the melting of iron in the cupola.—J. C. R.

The Replacement of Zhurinsk Coal by Other Types of Coal. V. I. Eremin. (Stal, 1948, No. 3, pp. 271–273). [In Russian]. Some coals which could replace Zhurinsk coal in the gas-generating plant in Ural metallurgical works are considered from the point of view of their technical properties.—S. K.

Meter for Flowing Mixtures of Air and Pulverized Coal. H. M. Carlson, P. M. Frazier, and R. B. Engdahl. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Feb., pp. 65–79). A meter has been developed for measuring the rate of flow of both constituents of mixtures of air and pulverized coal. It consists of two elements, a sharp-edged rubber orifice, to which coal does not adhere, for measuring the air, and a flow nozzle in series with it which measures the total air plus coal. The rate of coal flow is measured with an accuracy of $\pm$ 5% for coal/air ratios in the 0·5–1·4 range and coal sizes ranging from 75% to 92% through 200 mesh. The meter has been successfully used in vertical and horizontal pipes from $\frac{3}{4}$ to 4 in. in dia.
R. A. R.

The Application of Fuel Oil and Surplus Gas at an Integrated Iron and Steel Works. J. Sinclair Kerr. (Journal of the Institute of Fuel, 1948, vol. 21, Apr., pp. 165–176). A description is given of the utilization of surplus gases in an integrated iron and steel works. Stress is laid on the value of instrumentation and automatic control for obtaining consistent operating conditions and lowest heat consumptions. The use of fuel oil in place of producer gas for the firing of open-hearth furnaces is described in detail. An account is given of the instrumentation required for an oil-fired furnace. Experiences gathered in the application of fuel oil to these furnaces are described. A comparison is made between the results obtained with oil firing on the ordinary 50-ton basic open-hearth furnace and on an all-basic furnace of the same size fired by producer

gas. Some future trends in fuel-oil combustion technique are mentioned particularly with regard to problems of atomization.

The Thermal Efficiency and Economics of Oil Firing. G. R. Bashforth. (British Steelmaker, 1948, vol. 14, Apr., pp. 170–176). The application of oil-firing to the open-hearth furnace, soaking pits and reheating furnaces, and to tinning pots is discussed. Oil firing has many advantages: an over-all thermal efficiency greater than that achieved in the manufacture and use of producer gas, a higher flame temperature which promotes a shorter production time and therefore lower radiation losses, greater cleanliness in the absence of gas mains requiring periodical cleaning out, and a greater susceptibility to close control. Through these features increased output, lower labour costs and a longer working week can be obtained. Against these features must be set the dangers of more rapid attack on refractories, and of sulphur pick-up. At present, however, owing to the heat losses in most types of furnace, and the higher cost of oil fuel, the advantages cannot be attained unless thermal efficiency is increased by some 25%. The price of fuel oil is, moreover, not likely to fall with increasing world use, and factors affecting the application of oil firing will therefore be political and economic as well as technical. For integrated iron and steel works in Great Britain the best policy appears still to be the development of coke-oven and blast-furnace gas, relying on the national asset of coal deposits rather than on imported fuels.—J. P. S.

The Application of Automatic Stoker Firing to Silica Kilns. T. R. Lynam. (Symposium on Mechanical Firing: Transactions of the British Ceramic Society, 1948, vol. 47, May, pp. 173–176). Silica bricks can be heated to the required temperatures more quickly by automatic firing than by manual firing. At least three automatic stokers are recommended if fly-ash contamination is to be avoided.—M. A. V.

Coal Sizing and Coke Preparation. A. H. Fosdick and C. E. Underwood. (American Institute of Mining and Metallurgical Engineers: Blast Furnace, Coke Oven and Raw Materials Conference Proceedings, 1947, vol. 6, pp. 23–48). An account is given of the successive steps taken by the Bethlehem Steel Company to produce better blast-furnace coke from their available raw materials. These included the installation of coke-crushing and screening equipment, and fine-grinding of the coal. Diagrams of both machines and plant layout are included.—R. A. R.

Technical Developments in the Coal Industry. Some Recent Trends. (Mining Journal, 1948, Annual Review Number, Apr., pp. 49–53). Recently developed coal breakers and washers are briefly described.—M. A. V.

Notes on Coal Preparation. S. Lynch. (Journal of the Institute of Fuel, 1948, vol. 21, Apr., pp. 187–193). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 393.

Denby Hall Central Coal Preparation Plant. (Iron and Coal Trades Review, 1948, vol. 156, Apr. 23, pp. 833–843). A description is given of the new coal preparation plant at Denby Hall, Derbyshire, which has a capacity of about 500 tons/day. It incorporates Barvoys dense-medium separation, Hoyois trough-washing plant, and froth-flotation for the fines. Details of the organization and operating results are given.—R. A. R.

The Influence of Karagandinsk Coal on the Properties of Blast-Furnace Coke. P. A. Sudia and V. L. Krol. (Stal, 1948, No. 3, pp. 200–205). [In Russian]. The effects of additions of coal from the Karagandinsk basin to the usual coke-oven charge at Magnitogorsk are described, and an account is given of the properties of the resulting cokes and of their use in blast-furnaces. S. K.

National Tube Builds New Coke Plant at Lorain. (Iron and Steel Engineer, 1948, vol. 25, Apr., pp. 113–115). The National Tube Company has increased its coke-making capacity at Lorain, Ohio, from 850,000 to 1,650,000 tons per year. Three new batteries each of 59 ovens, underjet-fired and regenerative, have been installed with elaborate mechanical arrangements for charging, discharging, and quenching, while complex apparatus ensures the recovery of tar, ammonium sulphate, carbon disulphide, benzol, and naphthalene. J. P. S.

Coke Oven Machinery. R. Berg. (Iron and Steel Engineer, 1948, vol. 25, Apr., pp. 98–105). Modern methods of charging and discharging coke ovens are described, together with automatic reversing gear for air, gas, and waste-heat valves.—J. P. S.

Producer Gas, a Low-Cost Efficient Fuel. J. J. Swift. (Brick and Clay Record, 1947, vol. 111, No. 2, p. 48; British Ceramic Abstracts, 1948, Jan.–Feb., p. 13A). It is stated that maintenance costs of producer plants in the United States average 1 cent/million. B.Th.U. The two main types of producers are examined, and their working characteristics, design, installation cost, typical gas analysis, and thermal efficiency are discussed. Automatic control may be installed, and the need for careful selection of equipment for particular purposes is stressed.

Immersion Heating. M. J. Dewey. (American Gas Association: Industrial Heating, 1947, vol. 14, Nov., pp. 1822–1830, 1932; Dec., pp. 1992–2000, 2006; 1948, vol. 15, Feb., pp. 232–236). The development of immersion gas heating is reviewed and the equipment and some applications to modern industrial furnaces and metal baths are described.—R. A. R.

TEMPERATURE MEASUREMENT AND CONTROL

Automatic Temperature Regulation of Industrial Heating Installations. H. Baner. (Swiss Technics, 1948, No. 1, pp. 22–44). A number of thermostats of both the "on-off" and "progressive" types for various industrial purposes are illustrated, but complete technical descriptions are not given.—M. A. V.

Temperature Scale of the Blowing-Tube Bath Pyrometer. L. O. Sordahl and J. W. Bain. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 255–260). A comparison of temperature measurements of a steel bath made with a blowing-tube photoelectric-cell pyrometer and a platinum/platinum–rhodium quick-immersion thermocouple was made and good agreement obtained. Increases in the oxygen content of the nitrogen-air mixture blown through the tube of the former instrument caused increasingly high readings. R. A. R.

A Comparison of the Pt-PtRh Thermocouple with the Optical Pyrometer for Temperature Measurements in Liquid Steel. G. R. Fitterer and J. W. Linhart. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 289–297). Simultaneous temperature measurements of liquid acid open-hearth steel were made with a platinum/platinum–rhodium thermocouple and a potentiometer-type optical pyrometer. The readings with the latter instrument were consistently 35° to 50° F. above those with the former. The optical instrument was equipped with a 0·40 emissivity correction scale which was incorrect for the plain carbon steels in question; the true emissivity varied between 0·428 and 0·495.—R. A. R.

REFRACTORY MATERIALS

Application of Phase Equilibrium Data to High-Alumina Firebricks. B. V. Ivanov. (Ogneupory, 1946, vol. 11, No. 11–12, p. 25 [In Russian] : British Ceramic Abstracts, 1948, Jan.–Feb., p. 25A). An andalusite brick from the roof of an electric steel furnace was found to contain in the reacted zone, corundum, hercynite, and glass. Only a small amount of mullite was present. It is shown that this composition can be deduced from the FeO–Al_2O_3–SiO_2 diagram.

A Versatile Calorimeter for Specific Heat Determinations. H. Hill and R. M. Bell. (A.S.T.M. Bulletin, 1948, No. 151, Mar., pp. 88–91). An adiabatic colorimeter was constructed for determining the specific heat of insulating materials such as firebrick, glass, calendered linoleum, and various organic materials. The heating element is so constructed that the two parts of its winding may be connected in series or parallel to compensate for rapid charges of temperature such as occur on inserting the sample. The calorimeter cup itself consists of an aluminium alloy block. Four thermocouples in series, inserted in holes in the cup, are used to measure temperature changes. The whole instrument is heavily insulated. Its range is from below 100° C. for the linoleum and similar materials to about 1000° C. for firebrick and glass. Some specific heats recorded are (in cal./g./°C.) : For firebrick, 0·22, 0·25 and 0·27 ; for insulating firebrick 0·23, 0·28, and 0·31 at 200° C., 600° C., and 1100° C., respectively ; and for glass 0·24, 0·26, and 0·31 at 400° C., 600° C., and 900° C.—J. P. S.

The Measurement of Apparent Porosity and Bulk Density. A. H. B. Cross and P. F. Young. (Transactions of the British Ceramic Society, 1948, vol. 47, Apr., pp. 121–156). Part I describes experiments made in a study of soaking of porous materials by conventional methods involving evacuation to pressures between 0·3 in. and 2 in. Hg. It is shown that soaking *in vacuo* for 3 hr. is unnecessary since 80% of the pores are filled in a few minutes and 19% of the remaining 20% during the restoration of atmospheric pressure. A few minutes at atmospheric pressure after evacuation suffices to fill the pores almost completely (99·7%). Throughout the tests, a marked dependence of results on the degree of vacuum persisted, but the extent of this varied with individual samples.

Part II describes experiments made to achieve adequate soaking without resort to normal evacuation methods. The errors in "weight suspended" (W_B) and "weight soaked" (W_c) due to under-soaking are equal, though the actual W_c error may also contain an additional one due to wiping as shown in Part I. Prolonged boiling at atmospheric pressure achieves varying degrees of soaking, depending mainly on individual sample characteristics and requires too much time to be of practical value. A method has been developed which achieves almost complete soaking within a few minutes. This involves immersion of samples at 110° C. directly in boiling water at atmospheric pressure, followed by cooling to room temperature. Batches of determinations are again completed in ¾ hr. excluding weighings. Individual sample characteristics have been largely eliminated, and consistently better soaking leads to porosity results up to 0·6% greater.—R. A. R.

Performance of Silica Brick. K. D. Bartels. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 202–204). Experience in the use of an open-hearth furnace with a "split" roof (*i.e.*, made of two kinds of silica brick) is reported ; the low-alumina type gave poor performance, and roofs made of one type of brick were more satisfactory.
R. A. R.

Insulating Basic Furnaces. G. H. Johnston. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 204–205). Tests were made to ascertain the effect of insulation on basic brick end-walls of open-hearth furnaces. The basic bricks were metal-encased. With insulated brickwork iron oxide penetrated 2½ in. into the bricks after 40 heats when insulated, but only 1 in. without insulation. When the iron-oxide penetration reached 8·5% the brick broke off and the penetration recommenced.—R. A. R.

Basic Ends and Basic Roofs. A. K. Moore. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 206–207). Patching basic front and back walls of open-hearth furnaces has been successfully carried out with ground chrome ore using a Quigley gun. Successful experience with basic brick roofs is also reported.—R. A. R.

Basic Open-Hearth Installation, Ford Motor Company. W. J. Reilly. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 209–210). Experience with all-basic open-hearth furnaces is reported. No outstanding increase in production or decrease in fuel consumption has been noted.
R. A. R.

Basic Rammed Doors at Wheeling Steel Corporation. C. W. Drabers. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 210–212). The construction of the Sticker rammed basic door for open-hearth furnaces is described. In this, removable water-cooled rails retain the refractory which can be put in by unskilled labour.—R. A. R.

Trends in Bottom Construction. J. Topping and A. W. Robinson. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 214–217). Replies to a questionnaire on open-hearth furnace bottom construction and maintenance received from 40 plants are analysed.—R. A. R.

Mixer Linings—1000-Ton Stationary Hot-Metal Mixer. J. Hazel. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, p. 230). Experience in the use of sillimanite bricks for mixer linings is reported.—R. A. R.

Joint Erosion of Mixer Linings. K. D. Bartels. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 231–233). Experience indicates that blast-furnace quality firebricks set in a sillimanite-base mortar make the best mixer lining.—R. A. R.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Use and Production of Oxygen for Blast Enrichment. I—Use of Oxygen. W. A. Haven. (American Institute of Mining and Metallurgical Engineers : Blast Furnace Coke Oven, and Raw Materials Conference, Proceedings, 1947, vol. 6, pp. 50–55). The author has applied W. Lenning's data on the use of oxygen-enriched blast in German blast-furnaces (*see* Journ. I. and S.I., 1945, No. II, p. 179A) to American blast-furnace operating conditions, and finds that the use of oxygen at its present price of $58.00/ton would not be justified, assuming a consumption of 1870 lb. of coke per ton of low-silicon high-sulphur pig iron. He believes that with modern furnaces and equipment and raw materials beneficiated to the highest degree economically justified, their thermal and over-all efficiency will continue to be so high as to leave little room for improvement.—R. A. R.

Some Quantitative Aspects of the Use of Oxygen in the Iron Blast Furnace. R. J. Rocca and M. B. Bever. (American Institute of Mining and Metallurgical Engineers : Blast Furnace, Coke Oven, and Raw Materials

Conference, Proceedings, 1947, vol. 6, pp. 67–82). The literature on the use of oxygen in the blast-furnace is reviewed and calculations of the effect of oxygen enrichment are made by a method of analysis given in a paper by R. Rocca in Metallurgia Italiana, 1946, vol. 38, pp. 4–6. The conclusions reached were : (1) The volume of blast per ton of pig iron decreases with oxygen enrichment ; (2) the volume of top gas per unit of time increases unless the blowing rate is less than with normal air blast ; (3) the volume of gas in the bosh increases even if the blowing is adjusted to keep the volume of top gas at the normal value ; (4) the heat exchange in the furnace becomes more effective and can be achieved with lower furnace height ; (5) enrichment makes possible the reduction of top-gas temperature provided that in normal operation this temperature is above the necessary minimum ; (6) small degrees of enrichment may reduce the coke consumption because of the effect in conclusion (5), but greater enrichment increases the coke rate because of the decrease in sensible heat supplied by the blast ; (7) it is probable that the proportion of direct reduction is increased by enrichment ; (8) the increase in productive capacity and the resulting flexibility of operation constitute the chief advantages of using enriched blast ; (9) there is evidence that blast with about 30% of oxygen gives the optimum results in furnaces of current design ; and (10) while metal and slag temperatures remain substantially unchanged by oxygen enrichment, additional high-temperature heat becomes available for melting and hearth reactions, which is of interest in the production of ferro-alloys.

R. A. R.

Progress and Problems in Blast Furnace Design. C. G. Hogberg. (American Institute of Mining and Metallurgical Engineers : Blast Furnace, Coke Oven, and Raw Materials Conference, Proceedings, 1947, vol. 6, pp. 83–108). The development of blast-furnace profiles is reviewed. When large furnaces are designed to provide maximum volume within the practical limitations of bosh angle, inwall batter, and stockline diameter, neither production nor fuel economy is adversely affected. Various factors in design are correlated with actual performance data and a study of the relationships shows the importance of providing adequate volume in the lower zone of the furnace. The application of water-cooled plates in the area above the mantle is recommended to preserve the contour of the lining.

In an appendix a list is given of 28 parts and dimensions of a blast-furnace with a view to standardizing the nomenclature.—R. A. R.

Some Questions on Interrelated Processes Going on in the Blast Furnace. B. M. Larsen. (American Institute of Mining and Metallurgical Engineers : Blast Furnace, Coke Oven, and Raw Materials Conference, Proceedings, 1947, vol. 6, pp. 118–154). *See* Journ. I. and S.I., 1947, vol. 156, July, p. 436.

Some Blast-Furnace Experiences at Ymuiden, The Netherlands. F. W. E. Spies. (American Institute of Mining and Metallurgical Engineers : Blast Furnace, Coke Oven, and Raw Materials Conference, Proceedings, 947, vol. 6, pp. 155–176). An illustrated description is given of the iron and steel works of Koninklijke Nederlandsche Hoogovens en Staalfabrieken N.V., Ymuiden, Holland. Blast-furnace operating data are given and followed by details of a hearth break-out. The formation of salamander and scabs on the furnace shaft, and of their probable causes and measures taken to deal with them are discussed.—R. A. R.

Gas Production with a Single Blast-Furnace at Iron and Steel Works. 1. Operating a Blast-Furnace as a Gas Producer at a Merchant Ironworks. A. Reckmann. (Stahl und Eisen, 1948, vol. 68, Apr. 22, pp. 151–153). An account is given of the operation of a small blast-furnace near Lübeck for about nine months as a producer of gas for lighting and domestic purposes.—R. A. R.

Gas Production with a Single Blast-Furnace at Iron and Steel Works. 2. Operation and Experience with a Single Furnace. H. Pohl. (Stahl und Eisen, 1948, vol. 68, Apr. 22, pp. 153–156). In 1945 the Bochumer Verein, instead of working four blast-furnaces with an equalizing gasometer, were compelled to operate a single furnace with no gasometer. The measures adopted for the production, control, and maintenance of the gas supply are described.—R. A. R.

Gas Production with a Single Blast-Furnace at Iron and Steel Works. 3. Single-Furnace Operation at an Integrated Plant. H. F. Strähuber. (Stahl und Eisen, 1948, vol. 68, Apr. 22, pp. 156–158). The operation of a single blast-furnace at the integrated plant of Hüttenwerke Huckingen A.G., is described.—R. A. R.

Notes on Modern Blast-Furnace Technique. M. Brun and M. Legendre. (Métallurgie, 1947, vol. 79, Nov., pp. 7, 9–11 ; Dec., pp. 7–9 ; 1948, vol. 80, Jan., pp. 5, 7, 9 ; Feb., pp. 5, 7, 9, 10 ; Mar., pp. 5–7, 9 ; Apr., pp. 9, 11). The first three parts of this article deal with the preparation of the burden. The machinery used to crush and screen the ore is described and illustrated, and an account is given of different methods for blending, roasting, concentrating, and sintering the ore. The next three parts deal with the movement of ore and coke by trucks and conveyor belts, the size and location of storage places for raw materials, grabs and other mechanical devices which remove and weigh the raw materials, and skips and trucks which convey them to the blast-furnace.—J. C. R.

Blast Furnace Tapping Hole Construction. W. S. Unger. (Eastern States Blast Furnace and Coke Oven Association : Blast Furnace and Steel Plant, 1948, vol. 36, Apr., pp. 434–438). Full details are given of the improvements in iron-notch, slag-notch, and well-wall construction, incorporating carbon blocks, which have been carried out at the blast-furnaces of the Carnegie-Illinois Steel Corporation.—R. A. R.

The Properties of Blast Furnace Tapping Hole Refractories. L. L. Wells, jun. (Blast Furnace and Coke Association of the Chicago District : Blast Furnace and Steel Plant, 1948, vol. 36, Apr., pp. 451–454). The Carnegie-Illinois Steel Corporation is correlating blast-furnace tap-hole refractory properties with the service given by them. The present report compares the properties of the refractory mixes (fireclay, crushed firebrick, coke breeze, and water in varying proportions) charged into the clay gun at the different plants.

R. A. R.

Tuyere of Novel Design Improves Furnace Operation. J. H. Sprow. (Blast Furnace and Steel Plant, 1948, vol. 36, Apr., pp. 455–456). A description is given of a novel blast-furnace tuyere called the "double auger tuyere." It is 10 in. long and 5½ in. in dia., and the nose is constructed with eight ribs or vanes in two sets of four, one set extending from the back half-way along the bore, and the other, staggered to the first set to permit cleaning, in the front half of the bore. The pitch of the ribs imparts a 90° twist to the air stream. The blast penetrates further into the furnace ; more coke is burnt with the same amount of blast, and the coke consumption per ton of iron produced is less without detriment to quality.—R. A. R.

DIRECT PROCESSES

The Reduction of Iron Oxides with Hydrogen and Carbon Monoxide. H. J. Leibu. (Schweizer Archiv, 1948, vol.

14, Jan., pp. 1–19 ; Feb., pp. 49–59 ; Mar., pp. 76–85). The reduction of iron oxides in streams of hydrogen and of carbon monoxide has been investigated using firstly ferric oxide alone and secondly ferric oxide in the presence of other oxides of a gangue-like nature. The conclusions were : (1) A comparison of the equilibrium conditions at temperatures in the range of practical reduction with gases shows that hydrogen is the better reducing agent. (2) Except for unsteadiness at the transformation points, the reaction velocity in both cases increases with temperature, reduction being three to four times more rapid with hydrogen. (3) Below 800° C. CO is unstable and the reduced iron is high in carbon ; the dissociation of CO is accelerated by the catalytic action of the reduced iron. (4) The effect of grain size, porosity, and method of producing the ferric oxide, and the velocity of the reducing gases is similar for the two gases and is not of major importance. (5) The sulphur in sulphide iron ores is markedly reduced by hydrogen, but in the oxide ores the removal of sulphur proceeds much more slowly than the removal of oxygen ; thus in practice hydrogen does not remove much sulphur or phosphorus. (6) A combination of chemical and X-ray methods of analysis enabled Schenck's assumptions on the effect on the reduction of ferric oxide of the presence of other oxides to be checked ; the other oxides, when finely divided and intimately mixed with ferric oxide, delay the reduction and, at a certain degree of reduction, stop it entirely. (7) When the reduction was stopped it was found that a solid solution, or an intermediate type of crystal (" double oxides ") had formed either before or during the reduction. (8) The hindering action depends on the constitutional characteristics of the solid solution or new crystalline formation. (9) Almost complete reduction of the ferrites is obtained when iron is the only active cation, as in the case of calcium ferrite $2CaO.Fe_2O_3$ in which the calcium cation is inactive ; similar behaviour is to be expected with $Fe_2O_3.K_2O$, $Fe_2O_3.Rb_2D$, $Fe_2O_3.Cs_2O$, $Fe_2O_3.PbO$, etc. (10) Similarly almost complete reducibility can be easily obtained of the trivalent oxide of those ferrites the oxygen of which is mostly or entirely fixed by the iron, *e.g.*, magnesium ferrite [FeO_4MgFe]. (11) On the other hand, reduction is practically impossible when (*a*) the solid solution contains so little of the ferrous or ferric oxide that the (FeO_6), and possibly the (FeO_4) groups, are entirely surrounded by the octahedra or tetrahedra of the oxides of foreign cations, as for instance the iron-lean aluminium-rich $(Al.Fe)_2O_3$ and the iron-lean magnesium-rich (Mg, Fe)O solid solutions ; and (*b*) the intermediate crystalline formation, such as [SiO_4Fe_2] (Fayalite) or [FeO_4Al_2] in which each oxygen atom is not only a constituent of the groups (FeO_6) or (FeO_4), but also belongs to one (SiO_4) or three (AlO_6) groups. (12) The new method used in these investigations is important not only because it provides an explanation of the course of the reduction, but because it can be generally applied to determine and explain the influence of the crystalline structure on the behaviour of solid solutions and the relationship between different types of crystals, *e.g.*, Brownmillerite and $3.CaO.Al_2O_3$.—R. A. R.

PRODUCTION OF STEEL

The Dzerzhinski Metallurgical Works. N. M. Fomenko. (Stal, 1948, No. 1, pp. 72–76). [In Russian]. An account is given of the growth and reconstruction of the metallurgical works at Dnieprodzerzhinsk.—S. K.

Production of Carbon and Alloy Steels by the Side Blown Converter Process. F. Cousans. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A101–A107). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 468.

All Door Front Will Permit Use of Large Charging Boxes. L. S. Longenecker. (Blast Furnace and Steel Plant, 1948, vol. 36, Apr., pp. 447–450). The successful operation of seven large reheating furnaces with an " all door " front has led to the design of an open-hearth furnace with the front wall consisting of doors which can be lifted independently with no supports or guides between them. The proposed design is explained in detail and its advantages, particularly the possibility of using a charging box 10 ft. × 6 ft. × 3 ft. deep, are enumerated.—R. A. R.

Use of Sponge Iron for Making Steel in Sweden. M. Tigerschiöld and S. Eketorp. (American Institute of Mining and Metallurgical Engineers : Blast Furnace, Coke Oven, and Raw Materials Conference, Proceedings, 1947, vol. 6, pp. 177–194). This is an abridged translation of the paper by M. Tigerschiöld which appeared in Jerkontorets Annaler, 1947, vol. 131, No. 9, pp. 295–339 (*see* Journ. I. and S.I., 1948, vol. 158, Jan., p. 151). R. A. R.

Sponge Iron in Japan. T. L. Johnston. (United States Bureau of Mines, 1948, Information Circular No. 7440). Sponge iron was produced in Japan by the Krupp-Renn process in rotary kilns, from soft low-quality ores and sands, to the extent of 646,000 metric tons during the period 1939–45. The product " luppe " was melted in electric furnaces for steelmaking. Frequently containing nickel and chromium, the resultant material was of great use in saving important raw materials. Batch processes were not successful on the ores of the Japanese home islands, but were applied with good results to a high-grade magnetite concentrate at Penshihu in Manchuria.—J. P. S.

Refining with Oxygen at Gerlafingen. R. Durrer. (Von Roll Werkzeitung, 1948, vol. 19, May, pp. 73–74). A brief account of the first trials in Switzerland in the blowing of a Bessemer converter with oxygen is given. It was found that about 10 cwt. of cold scrap could be added to the 1-ton charge of molten iron as sufficient heat was generated to melt it.—R. A. R.

Oxygen in the Steel Industry. H. W. McQuaid and F. E. Pavlis. (Iron and Steel Engineer, 1948, vol. 25, Apr., pp. 41–48). The cost of oxygen has been greatly reduced by developments in generators, which have increased availability, and have improved the economics of the use of oxygen in the steel industry. In the largest units, cost reduction is sufficient to make possible the economic use of oxygen in the large open-hearth and the blast-furnace, while its use for scrap preparation, and maintenance, and for speeding up melting, carbon reduction, and bath conditioning is now a commercial proposition.—J. P. S.

The Duplex Process. D. T. Rogers. (Iron and Steel Engineer, 1948, vol. 25, pp. 49–58). The advantages of the duplex process employing the acid-Bessemer/basic-open-hearth sequence are described. Notably its saving of time over the conventional scrap/hot-metal process, which not only permits a greater tonnage output for a given furnace, but is of advantage to the ultimate steel quality. Control of temperature and time during the Bessemer blow and of the rate of carbon elimination in the open-hearth furnace permits production of duplex steel with nitrogen at a level comparable with the best scrap practice.—J. P. S.

The Search for an Effective Fuel-Oil Flame. B. I. Kitaev, N. I. Kokarev, D. K. Butakov, and S. P. Zamotaev. (Stal, 1948, No. 3, pp. 215–220). [In Russian]. After a consideration of the aerodynamical and chemical properties required of the open-hearth furnace flame,

various designs of cooled fuel-oil burners in the U.S.S.R. are compared with a number of those in use in the United States. It is concluded that further research is required to achieve more effective use of fuel oil in the open-hearth furnace.—S. K.

The Separation of Dust from Hot Gases in the Open-Hearth Furnace. J. Zimmerman. (Blast Furnace and Steel Plant, 1948, vol. 36, Apr., p. 459). To keep checker chambers clean and improve furnace efficiency it is suggested cyclone dust extractors be placed in the fantail section between the slag and checker chambers.—R. A. R.

Measurement of Differential Pressures on Open-Hearth Furnace Roofs. S. S. Carlisle and B. O. Smith. (Society of Instrument Technology: Iron and Coal Trades Review, 1948, vol. 156, Apr. 23, pp. 844–846). Details are given of an experimental pressure meter for measuring the pressure of hot gases in the open-hearth furnace. The measuring head is fitted close to the measuring point and electrical means are provided for remote indication of the readings.—R. A. R.

Proceedings of the Thirtieth Conference, National Open Hearth Committee of the Iron and Steel Division. (American Institute of Mining and Metallurgical Engineers, Open Hearth Proceedings, 1947, vol. 30). This Conference was held on April 21–23, 1947, at Cincinnati. It was attended by 826 representatives of the iron and steel industries of the United States and other countries. In addition to sessions on basic steelmaking practice and furnace maintenance there was also a session on cold-metal operations and basic steel foundry practice. Abstracts of the contributions to the Conference follow.—R. A. R.

Direct Oxidation. E. B. Hughes. (*Ibid.*, pp. 14–32). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 467.

Application of the Shaker Device to Medium Carbon Rimmed Steels. M. Geigel. (*Ibid.*, pp. 33–42). A description is given of a mechanical shaker for shaking ingot moulds during pouring in order to accelerate the removal of gas. It operates a platform carrying a track over which the ingot bogie moves; a cam lifts the platform 4 in. and allows it to drop back. The shaking can be adjusted between 24 and 50 bumps/min. Sections of shaken and unshaken ingots are shown for comparison. The device may be used either as a corrective measure on low-carbon rimmed heats or as a means of making rimmed steel of a higher carbon content. Heats can be tapped at a higher temperature when the shaker is used and the yield of steel from ingot to bloom is improved because the ingot obtained is more solid.—R. A. R.

A Program for Reducing Bottom Troubles on Basic Open-Hearth Furnaces. R. R. Fayles. (*Ibid.*, pp. 43–52). The reasons for the wear of open-hearth furnace bottoms are examined and details are given of the scheme adopted to reduce the time spent on repairs. The scheme included the appointment of a "bottom inspector" on each shift, resurfacing each furnace bottom at the beginning of every campaign, and accurately recording its performance. Details of the materials used for repairs and of the benefits obtained from the scheme are given.—R. A. R.

Preparation and Charging of Scrap. C. Denlinger. (*Ibid.*, pp. 53–61). Data on the cubic capacity of charging boxes and the weight of scrap per cubic foot of box at a number of steelworks are given and the use of larger boxes to increase the charging rate is advocated.—R. A. R.

Quality of Hot Metal. L. A. Lambing. (*Ibid.*, pp. 62–67). Higher percentages of hot metal are now charged in open-hearth furnaces in the United States so that the quality of the iron is now of greater importance. The effects of variations in the silicon, sulphur, phosphorus, and manganese are discussed, and the replies to a questionnaire on hot-metal quality are summarized. In the replies, 70% of the melting-shops specified 0·75–1·25% of silicon in the hot metal, 82% specified 1·00–2·25% of manganese, 90% specified 0·100–0·500% of phosphorus, and 92% specified 0·050% max. of sulphur. In duplex practice iron with a high silicon/manganese ratio tends to build up the converter lining, whilst a low silicon/manganese ratio leads to erosion.—R. A. R.

Use of Oxygen in Open-Hearth Furnaces. J. J. Golden. (*Ibid.*, pp. 68–74). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 142.—R. A. R.

Use of Oxygen at East Works, American Rolling Mill Company. H. V. Flagg. (*Ibid.*, pp. 74–82). This account relates to the use of oxygen for the combustion of oil in open-hearth furnaces. The oxygen is fed through a $\frac{3}{4}$-in. tube with a $\frac{5}{8}$-in. stainless steel tip positioned below the oil burner. The oxygen flow is 13,000–15,000 cu. ft./hr., and the fuel oil flow is 455 U.S. gal./hr. The average time up to making the hot-metal addition was reduced from 5 hr. 10 min. to 4 hr. 10 min. Turning on the oxygen brightens and shortens the flame which very quickly melts a trench through a fresh charge.—R. A. R.

Flush-Hole Maintenance. G. C. Lawton. (*Ibid.*, pp. 83–88). The maintenance of slag flush-holes in large open-hearth furnaces is discussed. Water-cooling in the flush-area has been discontinued at the Inland Steel Company's plant. A kennel-shaped cover extending over the first 2 ft. of the slag runner has been found advantageous. The runners, lined with raw dolomite and cement, are wide and shallow. The hole is closed when the slag level has subsided and the slag begins to thicken. On 145-ton and 175-ton furnaces it is best to maintain the bottom level of the flush hole 6 in. above the slag line.—R. A. R.

Bottom Maintenance. J. P. L. McMahon. (*Ibid.*, pp. 89–98). The construction and maintenance of open-hearth furnace bottoms is described. Magnesite mixed with open-hearth cinder, sometimes with ferrous oxide added, is used and sintered in layer by layer. Holes in the bottom are cleaned out with compressed air, if possible without resorting to silicon or aluminium. The bottoms build up when the furnace is fired with producer gas. Several low carbon heats usually clean a high bottom better than washing it; if scrap is charged through the middle doors and more limestone through the end doors, this tends to prevent the bottom from building up.—R. A. R.

Furnace Maintenance. G. H. Todd. (*Ibid.*, pp. 98–108). The results achieved by the furnace maintenance system applied to eight 150-ton open-hearth furnaces charged with a high proportion of hot metal are presented and discussed. The policy of two roofs per campaign has increased the campaign life by 32%, decreased furnace repair costs by 17%, increased running repair costs by 47%, decreased over-all maintenance cost by 2·5% and increased the tons produced per hour by 3·7%.

Use of New Mechanical Equipment—Survey of Devices. C. R. FonDersmith. (*Ibid.*, pp. 110–112.) Illustrations are given of mechanical equipment for facilitating furnace repairs and maintenance. They include elevator conveyors for bricks, scraper and mechanical shovels for cleaning out slag pockets, portable scaffolding, and a gun for spraying back-walls.—R. A. R.

Pig-Iron Substitutes in Basic Practice at Continental Steel Corporation. E. J. Nelson. (*Ibid.*, pp. 114–115). Charging petroleum coke in basic open-hearth furnaces when pig is scarce shortens the furnace life, especially that of the roof, and carbon is best added in the form of cast iron, when available. Spiegel and manganese ore are charged to supply the manganese.—R. A. R.

Pig-Iron Substitutes in Basic Practice at Luckens Steel Company. R. R. Fayles. (*Ibid.*, pp. 115–117). Sufficient 80% ferromanganese is charged to bring the total manganese up to that of a heat with a charge containing 25% of pig iron. Anthracite and by-product coke are used to make up the carbon; the amount of anthracite must be limited because the liberation of hydrogen causes violent foaming. The use of substitutes for pig iron does not directly affect the rate of production provided they do not cause foaming or raise the sulphur content too much. R. A. R.

Pig Iron Substitutes in Basic Practice—Cupola Iron As a Source of Hot Metal for the Open-Hearth. W. H. Steinheider. (*Ibid.*, pp. 117–119). Experience in the use of two large cupolas to supply hot metal for open-hearth furnaces, with special reference to the effects of changes in the scrap/pig-iron ratio on cupola operation, is reported.—R. A. R.

Pig Iron Substitutes in Basic Practice—Practice at Keystone Steel and Wire Company. A. E. Getz. (*Ibid.*, pp. 119–120). In charging coke, spiegel, and ferrosilicon as substitutes for pig iron these should be distributed so that the bath can absorb them as they melt, but not too deep to cause a long period of no action in the bath. It requires approximately 1000 lb. of coke and 12,000 lb. of scrap to replace 12,000 lb. of pig iron in the charge, and tap-to-tap heat time is increased by about 15–20 min. for each 1000 lb. of coke used per heat.—R. A. R.

Substitutes for Carbon Content—General Steel Castings Corporation. G. L. McMillin. (*Ibid.*, pp. 120–121). Experience in the use of coke to make up the carbon in the open-hearth furnace charge is reported. The methods of charging tried were (*a*) between the bottom scrap and the lime, (*b*) in the lime, (*c*) on top of the lime, and (*d*) on top of light turnings on the lime. The highest recovery of carbon was obtained with method (*d*).—R. A. R.

Use of Oil for Recarburizing Soft Melts. W. H. Carpenter. (*Ibid.*, pp. 123–125). The injection of oil has proved successful in recarburizing heats too low in carbon. The oil is injected through a ¼-in. pipeline through a wicket hole in the centre door. The oil must be flowing before inserting the pipe into the bath. The oil pressure is 170 lb./sq. in., and the rate of flow is 100 gal. (U.S.) in about 13 min. R. A. R.

Deoxidation Practice in Basic Steel Foundries. G. A. Lillieqvist. (*Ibid.*, pp. 128–138). The only deoxidizer which completely eliminates pinhole porosity in cast steel is aluminium. Titanium and zirconium are more efficient than silicon. There is practically no change in the reduction of area and elongation of the steel with increase in the aluminium addition from ¾ to 2½ lb./ton, but there is a sharp drop in both values when only ½ lb./ton is added. The aluminium is added when the ladle is about half full, after the silicon and manganese additions. Adding selenium or tellurium with the aluminium causes the inclusions to be round rather than crystalline. The iron oxide in the slag should be 12–15%; with a greater proportion, eutectic inclusions are formed, and with less there is danger of phosphorus passing back into the iron.—R. A. R.

Hydrogen in Cast Steel. C. E. Sims. (*Ibid.*, p. 138). The removal of hydrogen from molten steel varies from furnace to furnace, but very vigorous boiling is required to reduce the hydrogen appreciably. Improperly dried ladles are a frequent source of hydrogen. Although steel may be very high in hydrogen when poured, test-pieces from it may contain very little. The effect of hydrogen on the properties of steel depends more on the mode of concentration than on the quantity present.—R. A. R.

Fluidity of Furnace-Killed *vs.* Ladle-Killed Basic Open-Hearth Heats. D. J. Murphy. (*Ibid.*, pp. 139–140). The practice of killing with 16% ferrosilicon, adding spiegel 5 min. later, and tapping after a further 10 min. sometimes led to poor fluidity; this could be avoided by leaving the spiegel longer in the furnace. With manganese-titanium steels, it was found best to put all additions in the ladle. In making chromium steel for armour plate, best results were obtained by killing with ferrosilicon and adding chromium in the furnace, but allowing the heat to open up a little before tapping.—M. A. V.

Steel Quality and Steel Castings. C. B. Jenni. (*Ibid.*, pp. 143–145). *See* p. 330

The Mechanism of the Carbon-Oxygen Reaction in Steelmaking. C. E. Sims. (*Ibid.*, pp. 146–159). *See* Journ. I. and S.I., 1947, vol. 156, May, p. 132.

The Cenco-Derge Rapid Oxygen Determination. J. H. Richards. (*Ibid.*, pp. 160–168). *See* p. 347.

Furnace Deoxidation in Basic Open-Hearth Practice. W. O. Philbrook. (*Ibid.*, pp. 168–179). Recent papers on deoxidation practice are reviewed and the author concludes that: (1) Heavy additions of ferromanganese have little effect on the oxygen content of the steel; (2) the cost of the addition is greater than the return in terms of the increased recoveries of manganese and silicon; and (3) the time required for obtaining the results of a bath analysis should be reduced so that there is no need to "block" the heat (*i.e.*, make an addition to stop the oxidation of the carbon).—R. A. R.

A Rapid Spectrographic Control Method for Determination of Lime Silica Ratios in Open-Hearth Slags. J. F. Woodruff. (*Ibid.*, pp. 179–186). *See* p. 348.

Temperature Considerations in the Solidification of Killed Steel Ingots. J. W. Spretnak. (*Ibid.*, pp. 187–194). Data in the literature relating to the effect of the following factors on the solidification of steel ingots are reviewed: (1) Degree of superheat at pouring; (2) initial mould temperature; and (3) thickness of the mould wall. (*See* Journ. I. and S.I., 1947, vol. 156, July, p. 437).—R. A. R.

Use of Water on Hot-Topped Steel at the Pouring Platform. G. W. Humes. (*Ibid.*, pp. 194–196). In the water-treatment of ingots the big-end-down moulds, with clay tops in place, are poured as usual; fine anthracite is placed on the hot tops immediately afterwards. About 40 min. after pouring the hot tops are filled with water. This boils away after several minutes; the treatment is repeated twice. The three treatments cause a heavy bridge of steel to form across the bottom of the hot top which is sufficiently strong to take the thrust of the stripper ram. The ingots are promptly stripped and sent to the soaking pits. The time from pouring to charging in the pits is 1–1½ hr. Little or no fuel is used on the pits for the first 30 min. after charging. Ingots are ready for rolling 2 hr. after charging. This treatment has been successfully applied to thousands of tons of 0·62–0·68% carbon steel. The advantages include: (1) Holding time is greatly reduced, thus freeing the pouring platforms for other heats; (2) ingots are

hotter when charged in the soaking pits; (3) the throughput of pits is increased and less fuel is required; (4) the life of ingot moulds and stools is increased; (5) rolling-mill delays while waiting for steel are lessened; and (6) the amount of scrap on cropping is reduced.

A split water-treated ingot shows piping below the hot top, but this pipe is very clean with shiny, easily welded surfaces. This pipe is separated from the hot-top pipe by the solidified bridge which serves as a barrier to the non-metallic inclusions.—R. A. R.

Manufacture of Open-Hearth Steel to Hardenability Specifications. F. M. Washburn. (*Ibid.*, pp. 197–201). The H-steels are those falling within the hardenability-band specifications set up by the American Iron and Steel Institute and the Society of Automotive Engineers. Methods of producing these steels are described. In general, it is recommended that end-quench hardenability test data be obtained on specimens cast when the heat is teemed, and the steel allocated in accordance with the results. Another method is to make additions calculated to bring the hardenability to the mean value of the "band."—R. A. R.

Performance of Silica Brick. K. D. Bartels. (*Ibid.*, pp. 202–204). *See* p. 323.

Insulating Basic Furnaces. G. H. Johnston. (*Ibid.*, pp. 204–205). *See* p. 323.

Basic Ends and Basic Roofs. A. K. Moore. (*Ibid.*, pp. 206–207). *See* p. 323.

Basic Open-Hearth Installation, Ford Motor Company. W. J. Reilly. (*Ibid.*, pp. 209–210). *See* p. 323.

Basic Rammed Doors at Wheeling Steel Corporation. C. W. Drabers. (*Ibid.*, pp. 210–212). *See* p. 323.

Trends in Bottom Construction. J. Topping and A. W. Robinson. (*Ibid.*, pp. 214–217). *See* p. 323.

Comparison of Tests for Bulk Density of Fired Ramming Materials, and a Description of a Test for Magnesite-Slag Mixes. R. B. Snow and C. E. Sumpter. (*Ibid.*, pp. 217–221). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 464.—R. A. R.

Air-Chamber Checkers. B. L. Dorsey. (*Ibid.*, pp. 222–224). The design and maintenance of air checker chambers 21 ft. long × 12 ft. 10 in. wide, some 11 ft. and others 16 ft. deep, are described.—R. A. R.

Size Variation in Checker Brick and Its Effect on Open-Hearth Checker Life. J. A. Pierce. (*Ibid.*, pp. 223–230). Difficulty in the construction of checker brickwork of the closed vertical flue type due to non-uniformity in brick dimensions is discussed and statistics on the variations in brick dimensions are presented.—R. A. R.

Mixer Linings—1000-Ton Stationary Hot-Metal Mixer. J. Hasel. (*Ibid.*, p. 230). *See* p. 323.

Joint Erosion of Mixer Linings. K. D. Bartels. (*Ibid.*, pp. 231–233). *See* p. 323.

Control of Sulphur in the Open-Hearth. G. L. Plimpton. (*Ibid.*, pp. 234–238). The answers to a questionnaire on the elimination of sulphur in open-hearth steel are analysed. In the Chicago district most of the sulphur is attributed to the quality of the scrap. All works increase the slag basicity by adding limestone or burnt lime. There appears to be no relationship between the carbon and sulphur contents when all the charge has melted.—R. A. R.

Mold Practice. L. R. Berner. (*Ibid.*, pp. 245–249). The replies to a questionnaire on ingot-mould practice are presented and discussed.—R. A. R.

Mold Practice at Jones and Laughlin. J. F. Pollack. (*Ibid.*, pp. 249–250). Redesigning ingot moulds so as to reduce the difference in wall thickness between the bottom and the top greatly increased the mould life. Experiments are in progress on the use of graphite stool inserts, tests so far have indicated that these eliminate "stickers."—R. A. R.

Temperature Scale of the Blowing-Tube Bath Pyrometers. L. O. Sordahl and J. W. Bain. (*Ibid.*, pp. 255–260). *See* p. 322.

Effect of Nozzle Size on Surface Quality of Slab Product of Low-Carbon Rimmed Steel. C. Hunter. (*Ibid.*, pp. 260–266). An investigation is described which showed that increasing the pouring rate by increasing the nozzle diameter in the 2–4 in. range considerably improved the surface quality of slabs of low-carbon steel cast in moulds of large cross-section.—R. A. R.

Hot Tops in Relation to Ingot Soundness. E. W. Pierce. (*Ibid.*, pp. 267–271). Tests were made to determine the effect of different types of refractory hot tops on the pipe and inclusions in 0·45% carbon steel ingots poured in 25 × 25 × 71-in. big-end-up moulds. The results indicated that hot tops enclosing a volume of 14·5–15·5% of the mould were satisfactory.—R. A. R.

Washing or Flushing Acid Open-Hearth Steel with Inert Gas. P. M. Hulme. (*Ibid.*, pp. 273–281). Methods of flushing molten steel with nitrogen or argon to remove hydrogen are described and data on the theoretical amounts of gas required to remove given volumes of hydrogen are presented. The flushing is also beneficial in bringing solid impurities up into the slag.—R. A. R.

A Direct Reading Spectrometer for Ferrous Analysis. S. H. Walters. (*Ibid.*, pp. 281–289). *See* p. 348.

A Comparison of the Pt-PtRh Thermocouple with the Optical Pyrometer for Temperature Measurements in Liquid Steel. G. R. Fitterer and J. W. Linhart. (*Ibid.*, pp. 289–297). *See* p. 322.

The Modern Electric Arc Steel-Melting Furnace. B. S. Barskii and A. F. Myrtsymov. (Stal, 1948, No. 3, pp. 223–232). [In Russian]. Modern electric arc steel-melting practice in the U.S.S.R., the U.S.A., and Germany are compared and the various factors involved in the process are discussed.—S. K.

Automatic Control of Arc Furnaces. L. Bemporad. (Ingegnere, 1947, Oct., pp. 723–733. [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 30). The following aspects of the control of arc furnaces for melting and refining steel are considered: Classification of regulators, control difficulties with electric furnaces, hand regulators and power controls, and control by electromechanical or electrohydraulic servo-motors.

Advances in British Steel Casting Technique. (British Steelmaker, 1948, vol. 24, Apr., pp. 159–164). The works of Messrs. K. & L. Steelfounders & Engineers, Ltd., at Letchworth, is described. Plant includes two 5-ton electric-arc furnaces, one basic, of which the hearth is of rammed dry graphitized dolomite and the roof of silica brick, and one acid, with a bottom rammed with pure silica-sand mixed with 4% of clay. The average analysis of steel from the basic furnace is C 0·22%, Mn 1·5%, Si 0·25%, S 0·024%, P 0·027%; from the acid furnace C 0·20%, Mn 0·84%, Si 0·41%, S 0·034%, P 0·042%. Brief reference is made to casting-shop practice and to heat-treatment. Extensive and up-to-date metallurgical laboratories are maintained.—J. P. S.

FOUNDRY PRACTICE

We Visit the Works of the Staveley Coal and Iron Company, Ltd. (Contractors Record, 1948, vol. 59, May 19, pp. 16, 19, 21–26). An illustrated description is given of plant and operations at the Staveley foundries.

M. A. V.

Gray Iron Foundry Modernised. V. E. Hillman. (American Foundryman, 1948, vol. 17, Mar., pp. 84–89). Intensive mechanization has been carried out at the foundry of the Crompton and Knowles Loom Works, Worcester, Mass. Most of the moulding is now done on squeezer or roll-over machines, moulds are poured in "train loads" from trolley ladles and sand is mechanically conditioned for re-use. Castings are normally made from gray iron, but where subsequent hardening is required at certain areas, the iron is inoculated, with ferrochromium, ferrosilicon or copper, in the ladle.
J. P. S.

The Modernization of Small and Medium Foundries, with a View to Increasing Production. C. W. Schwenn. (Fonderie, 1946, Special Issue, pp. 464–465).

The Influence of Production Flow on Moulding Methods in Iron Foundries and Its Effects on P.M.H. and General Efficiency. R. C. Shepherd. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A169–A200). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 634.

Control in a Mechanised Jobbing Steelfoundry. D. Brown. (Proceedings of the Institute of British Foundrymen, 1947–47, vol. 40, pp. B93–B98). *See* Journ. I. and S.I., 1947, vol. 155, Apr., p. 629.

Cupola Operation with Heated Blast. S. W. Healy. (American Foundryman, 1948, vol. 13, Mar., pp. 44–45). Hot blast for cupolas may be obtained by burning either external fuel or the waste gases from the stack, in a heat exchanger, or by utilizing the sensible heat of the stack gases by circulating the air for combustion through tubes or chambers round the cupola shell. Advantages of hot-blast melting are: (1) Considerable saving in coke (15–20% is claimed as a conservative estimate); (2) a faster melting rate, as a result of more efficient combustion of coke; and (3) a hotter and more fluid metal is produced. As hot-blast melting reduces the tendency of elements, such as silicon and manganese, to burn out, the steel in the charge may be increased by up to 20% which will also control shrinkage.—J. P. S.

Small Foundries Can Engage in Research and Development. H. Czyzewski. (American Foundryman, 1948, vol. 13, Mar., pp. 54–56). The danger to the small foundry business of competitive fabrication methods can be met by research, by (1) individual firms, (2) associations of producers, (3) associations of users, (4) combinations of users and producers, and (5) the over-all metal-industry associations.—J. P. S.

Experimental Contribution to Mechanization in General Mechanical Foundry Practice. E. Lecœuvre. (Fonderie, 1946, May, pp. 177–188). Between the two great wars mechanization was increasingly introduced into French foundries. Illustrated descriptions of large castings produced by a French foundry during this period are given. It is now manufacturing locomotive cylinders and lathe-beds; the method of production, the number of workers employed, and the time taken for each stage of production, are outlined.—J. C. R.

Modernized Foundry Stresses Good Working Conditions. E. Bremer. (Foundry, 1948, vol. 76, May, pp. 120–124, 280, 282, 284). The foundry of Fairbanks, Morse & Co., Freeport, Illinois, has been completely reconstructed, and a high degree of mechanization, with attention to dust and fume removal, makes working conditions easier for the operatives. The sole raw material of the plant is cast-iron borings, which, with sprues and reject castings are melted continuously in an electric-arc furnace, which is tapped into 400-lb. ladles. About 40 tons of castings are produced per day. A synthetic moulding sand is used to which bentonite, seacoal, wood-flour, and moisture are added as required.—J. P. S.

Production of Cast Iron Having a High Graphite Content. (Fonderie, 1946, May, pp. 191–192). Some notes on the production of cast iron for bearings are given. A suitable composition is shown as C 3·50–3·80%, Mn 0·6–0·8%, S <0·10%, P <0·30%, with silicon varying from 1·90%, when the casting was 5 mm. thick, to 1·50% when it was 20 mm. thick. The graphite content should be high to assist lubrication, and to promote this condition it is desirable for the iron to contain 0·10–0·20% of titanium.—J. C. R.

Iron Foundry: Allocation of Storage Space, Determination of the Composition of the Burden. (Fonderie, 1946, May, pp. 192–194). Brief notes are given on the orderly distribution of raw materials and stocks of iron in storage places, and on the determination of the composition of the burden according to the product required.
J. C. R.

The American Foundry. R. Kenner. (Fonderie, 1946, July, pp. 247–259). A detailed review is presented of current American foundry practice.—J. C. R.

Rotary Melting Furnaces. P. Blanchard. (Fonderie, 1946, Oct., pp. 323–334; Nov., pp. 365–374). After briefly referring to electric rotary furnaces, the author gives a detailed and illustrated description of various types of rotary reverberatory furnaces. Particular attention is paid to the technique of heating, control of the operating temperature, heat transfer between the flame and the metal bath, the choice of pulverized coal, oil, gas or mixtures of these as the fuel, refractory linings, and output of the furnaces.—J. C. R.

Use of Fuels Other than Coke for Various Heating Purposes in a Foundry. P. Nicolas. (Fonderie, 1946, Oct., pp. 351–352). Brief notes are given on fuels, alternative to coke, that are suitable for heating purposes in the foundry.—J. C. R.

Gas for High-Grade Iron Production. A. G. Arend. (Coke and Gas, 1948, vol. 10, Apr., pp. 147–148). It has been found economical to prepare high-grade iron for rolls and centrifugally cast pipes in a molten 100-ton tilting open-hearth type mixer, with Moll-type furnace heads, fired with mixed blast-furnace and coke-oven gas. Ladles charged with foundry pig iron are transported to the mixer from which a sufficient quantity of non-graphitic iron is added to yield a product of the required composition. Constructional and operating details are given, and heat losses are analysed. The total heat consumption varies very little with the throughput of metal.—M. A. V.

Recent Technical Developments in the Production of Iron Castings. E. C. Dickinson. (Institute of British Foundrymen: Foundry Trade Journal, 1948, vol. 84, Apr. 8, pp. 341–344; Apr. 15, pp. 369–370). The foundry developments which are reviewed in this paper include: (*a*) The properties of "Nodulite," the cast iron with graphite in nodules instead of flake form; (*b*) shot-blast cleaning; (*c*) complete removal of core sand in dilute hydrofluoric acid; (*d*) removal of scale and rust by molten caustic soda with a little sodium hydride; (*e*) use of aromatic residues as a partial substitute for linseed oil; (*f*) infra-red heating; (*g*) dielectric heating and the effect of core wires; and (*h*) high-frequency heating of dry cores bonded with molasses and linseed oil.—R. A. R.

Difficulties in Machining Cast Irons. G. Joly. (Fonderie, 1946, Dec., pp. 416–419). The difficulty of machining cast iron is often due to the manganese content being too low when related to the sulphur content, and it is suggested that the manganese content should be between 0·6% and 0·7%. The silicon content should be related to the phosphorus and the thickness of the casting. Results are shown of tests carried out to determine the

depth of hardness penetration in its relationship to silicon content.—J. C. R.

Desulphurisation and Dephosphorisation of Molten Cupola Iron and Pig Iron in Basic-lined Ladles. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B14–B40). *See* Journ. I. and S.I., 1947, vol. 156, Aug., p. 575, and 1948, vol. 158, Feb., pp. 201–208.

Oxygen Enrichment of the Cupola Blast. A. K. Higgins. (Iron Age, 1948, vol. 161, Apr. 22, pp. 72–77). Two trials in a 36-in. cupola using air enriched to 25% of oxygen show that: (1) Over-all melting rate is increased by a large factor, of the order of 2; (2) initial melting time is reduced by 20%; (3) metal temperatures are increased by 100° F. (55° C.) or more; and (4) the composition of the metal may be altered, as silica is reduced to silicon. It is suggested that, though the excessive temperatures produced by the *continued* use of oxygen are beyond the useful range of cupola refractories, oxygen could well be used as a "booster" for the first tap of the day's operations.—J. P. S.

The Automatic Charging of Small Cupolas. R. Lesage. (Fonderie, 1946, Oct., pp. 346–351). Descriptions are given of different types of drop-bottom and drop-side conveyors, and an account is presented of their use in the automatic charging of cupolas.—J. C. R.

Drying and Lighting a Cupola with an Oil Burner. P. Nicolas. (Fonderie, 1946, Nov., p. 385). A description is given of an oil burner, using compressed air, suitable for drying the lining of the cupola and firing the coke charge. The advantages claimed are: Saving of wood fuel; reduction of 25% in the amount of coke used to dry and fire the cupola; economy of labour; and absence of ash which results from the use of wood fuel, this being detrimental to the lining.—J. C. R.

Dimensions and Shape of Cupola Tuyeres. G. Joly. (Fonderie, 1946, Special Issue, p. 468).

Measurement of Cupola Air Supply. (Foundry Trade Journal, 1948, vol. 84, Apr. 22, p. 395). Instruments are described for either indicating the volume of cupola blast or both indicating and recording it. The latter type of instrument can be provided with automatic controls to govern either rate of flow or pressure.
J. P. S.

Cupola/Reverberatory-Furnace Duplex Practice in the United States. J. Lainé. (Fonderie, 1946, Nov., p. 384). Brief details are given of the practice at two foundries, at one of which castings are rapidly annealed in a bell-type electric furnace, and at the other annealing takes place in an oil-fired tunnel furnace.—J. C. R.

Cast Irons for Ingot Moulds. G. Joly. (Fonderie, 1946, Oct., pp. 345–346). A brief note is presented on the composition of cast irons which have good mechanical properties and are growth-resisting, to be used for ingot moulds.—J. C. R.

The Annealability of White Iron in the Manufacture of Malleable Iron. S. W. Palmer. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A64–A86). Journ. I. and S.I., 1947, vol. 157, Dec., p. 475.

Annealing Malleable Iron. R. P. Schauss. (American Foundryman, 1948, vol. 13, Mar., pp. 34–38). This paper describes both batch and continuous processes for the annealing of malleable iron; reference is made to both muffle and radiant tube methods of heating.
J. P. S.

Welding and Cementation of European [White Heart] Malleable Iron. (Fonderie, 1946, July, pp. 266–267). Brief notes are given on welding and cementation of whiteheart malleable iron and the circumstances in which these processes can be successfully applied.
J. C. R.

Mass Production Methods Applied to the Manufacture of Cast Steel Bomb Bodies. P. H. Wilson. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A108–129). *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 469.

The Production of Steel Castings for Aeroplane Construction. R. Buquet. (Fonderie, 1946, Dec., pp. 397–415). The use of cast steel for aeroplane construction was developed during the war years. Progress made in the United States and Britain is reviewed and a more detailed account is given of the use of cast steels in the production of German aircraft. Analyses of the steels employed, their mechanical properties, and methods of production and heat-treatment are outlined.—J. C. R.

Steel Quality and Steel Castings. C. B. Jenni. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 143–145). The danger of liquid steel taking up hydrogen when poured into green-sand moulds, and the necessity for close control of the sulphur and phosphorus are stressed. Removal of the phosphorus is promoted by a decrease in temperature, high iron-oxide content in the slag, and high slag basicity.—R. A. R.

Modernization of an Automatic Sand Preparation Plant. (Fonderie, 1946, June, pp. 232–234). Illustrated alternative plans are shown for the modernization of an automatic sand preparation plant.—J. C. R.

Foundry Sands for the Production of Cores and Dried Moulds and the Green Sand Casting of Small Parts. (Fonderie, 1946, Aug.–Sept., pp. 303–305). An account is given of the characteristics of some French foundry sands and of suitable mixtures for cores and moulds.
J. C. R.

Sampling of Sands Submitted for Testing. P. Nicolas. (Fonderie, 1946, Nov., p. 383). A brief note is presented on the sampling and testing of foundry sands.—J. C. R.

Expansion of Silica Sand. H. H. Fairfield. (Foundry, 1948, vol. 76, May, pp. 128–129). A rapid expansion takes place in silica sand at 590° C. which will cause cracking and spalling of mould faces at that temperature. The admixture of cellulose materials such as wood-flour, powdered corn-cobs and so on reduces this danger, as these materials not only shrink on heating, but also burn out and leave voids. A description is given of a dilatometer apparatus for measuring the expansion of foundry sands.—J. P. S.

The Flowability of Moulding Sand with Special Reference to the Shatter Test. E. L. Graham. (Institute of British Foundrymen; Foundry Trade Journal, 1948, vol. 84, Apr. 15, pp. 365–367). This is an abridged account of a lecture on the "Shatter Tester" and the results obtained with it on numerous green and synthetic sand mixtures. Recommendations are made for sands for light, medium, and heavy iron and steel castings.—
R. A. R.

The Use of Mixed Foundry Sand Binders. L. Jenícek. (Fonderie, 1946, Special Issue pp. 462–463). A summary is presented of a paper in which the author surveys the use of various inorganic and organic binding agents, and mixtures of them with foundry sands.—J. C. R.

Patternmaking—A New Machine for Cutting Irregular Shapes. B. Levy. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B70–B76). *See* Journ. I. and S.I., 1947, vol. 156, Aug., p. 576.

Influence of Design and Pattern-Making on Foundry Technique. T. H. Sneddon. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B83–B92). *See* Journ. I. and S.I., 1947, vol. 155, Apr., p. 576.

Casting in Moulds with Cement-Sand Cores. P. I. Ulitenko. (Stal, 1948, No. 3, pp. 264–267). [In Russian]. An account is given of tests in which a core mixture

consisting of 90% sand and 10% Portland cement, with a total of 9% moisture, was used for the production of hollow steel castings weighing up to 5½ tons. The preparation of the moulds and cores, the composition and properties of the sand, cement, and the mixture, and the properties of the castings are described, the following conclusions being drawn : The drying of sand, mould, and core is avoided by the use of cement-sand mixtures, resulting in considerable economy ; economy also results from the fact that cement is cheaper than the usual binders ; ramming and finishing are simpler with cement-sand mixtures, and the resulting castings are cleaner, more free from blowholes, and stronger than those produced with the usual materials.—S. K.

Some Notes on Feeding. S. L. Finch. (Proceedings of the Institute of British Foundrymen, 1947–48, vol. 40, pp. A87–A100). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 635.

A New Range of Moulding Machines. J. H. Hufton. (Foundry Trade Journal, 1948, vol. 84, Apr. 29, pp. 419–420, 425). A new range of large moulding machines for use with boxes in the region of 10 ft. × 5 ft. × 3 ft. has been introduced by Messrs. Stone-Wallwork, Ltd. They are of both turn-over and straight-draw types, for use either with shockless jolters integral with the machine or with sandslingers. The turnover and lift mechanisms are hydraulic ; oil is the operating medium and each machine has its own self-contained hydraulic unit.—J. P. S.

Some Notes on the Surface Drying of Moulds. A. Cracknell and F. Cousans. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A201–A217). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 635.

Cores with Coal-Tar-Pitch. P. I. Shportenko. (Stal, 1948, No. 3, pp. 268–271). [In Russian]. An account is given of a successful investigation into the possibility of applying coal-tar pitch in the foundry as a core-binder, with particular reference to the following points : Amount of gas produced by coal-tar pitch mixtures and the effect of this on the quality of the casting ; their screen analysis, giving the necessary porosity ; the effect on the cohesion of mixtures of the pitch at high temperatures and under considerable hydrostatic pressure by the metal ; the strength of the cores after drying and their behaviour during casting (*i.e.*, pliability and thermal stability) ; the hygroscopic nature of coal-tar pitch cores, their adhesion to the pattern and their ability to retain a given shape. The coal-tar pitch was introduced into the core mixture either as an emulsion or as a fine powder. It is stated that certain other materials, such as manure, sawdust, coal, etc., give satisfactory cores when added to silica sand.—S. K.

Venting of Cores and Moulds. D. Killingworth. (Foundry Trade Journal, 1948, vol. 84, Apr. 22, pp. 389–394). The problem of venting cores and moulds is discussed with relation to the amount of gas to be vented and the permeability of the moulding materials.—J. P. S.

The Manufacture of Ingot Moulds for Steelworks. A. Charmeau. (Fonderie, 1946, Special Issue, pp. 446–452). An account is presented of the qualities required in ingot moulds and the factors that lead to their attainment. The causes of cracking and of disintegration of the inside walls of the moulds are surveyed. An outline is given of the practice of manufacturing ingot moulds, and an account is given of researches undertaken with a view to improving their service life. J. C. R.

Ferrous Die Castings. C. D. Pollard, H. A. Redshaw, and C. A. Payne. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A30–A46). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 635.

Centrifugal Casting. L. Northcott. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B77–B82). *See* Journ. I. and S.I., 1947, vol. 156, Aug., p. 576.

The Present Position of Centrifugal Casting in the Foundry. J. Boucher. (Fonderie, 1946, Special Issue, pp. 435–437). Brief details are given of modern centrifugal casting practice.—J. C. R.

Centrifugal Casting of Cylinder Liners. (Fonderie, 1946, Aug.–Sept., pp. 306–307). A brief note is presented on the centrifugal casting of plain and special cast-iron cylinder liners.—J. C. R.

Introduction to the Study of Foundry Defects. F. Boussard. (Fonderie, 1946, Special Issue, pp. 431–434). An account is given of a classification system for foundry defects, which are grouped according to their appearance and their cause. The latter class is sub-divided under metallurgical factors and factors which arise directly from casting practice. Each factor is then split up into the various items that may cause defects.—J. C. R.

Gases in Cast Metals. M. R. Bever. (American Foundryman, 1948, vol. 13, Mar., pp. 90–94). The theory of gas-metal interaction from the standpoint of unsoundness, and the origin of gases in casting operations are reviewed. It is suggested that the laws of such interaction and the causes and prevention of unsoundness are understood and that the application of the knowledge is still a challenge to the operating metallurgist.—J. P. S.

Economics of Castings Use. E. Laitala. (American Foundryman, 1948, vol. 13, Mar., pp. 48–51). There are certain factors which indicate when it is most economical to use castings—function, quality, cost, necessity to meet delivery dates, and appearance. Application of these factors can also be made to any other manufacturing process.—J. P. S.

Piece-Work (Standardizing) in General, and Piece-Work in Foundries. K. Stastný. (Hutnické Listy, 1947, vol. 2, No. 5, pp. 99–103 ; No. 6, pp. 124–128). [In Czech].

Installation of a Foundry School. (Fonderie, 1946, July, pp. 270–277). Details are given of a suggested layout and equipment for a foundry school.—J. C. R.

Education in the Foundry. J. B. Longmuir. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B60–B65). The paper can be regarded as a continuation of an earlier one "Apprentice Training in the Foundry" (*see* Journ. I. and S.I., 1946, No. II. p. 22A). The training of apprentices in the foundry is discussed, its value and cost are dealt with, and practical recommendation are made.—R. A. R.

Foundry Safety and Hygiene. R. J. Wolf. (American Foundryman, 1948, vol. 13, Mar., pp. 25–33). Precautions for safety in foundries, with especial reference to cranes and hoists, the use of goggles and respirators in dusty atmospheres, and the care and maintenance of oxygen and acetylene cylinders are discussed.—J. P. S.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat-Treatment of Steels and Various Alloys. Recent Progress. Sourdillon. (Technique Moderne, 1947, May 1–15, pp. 168–174 ; July 1–15, pp. 237–241 : [Abstract]. Chaleur et Industrie, 1948, vol. 29, Mar., p. 15D). The following aspects of heat-treatment are included in this review : Controlled atmospheres, cementation, hardening, gaseous cementation (Renault process), surface hardening, flame hardening, and induction hardening. The treatment of heat-resistant alloys for gas turbines (resistant to temperatures up to 800° C.

after treatment), low temperature treatment and mechanical treatment by shot-blasting are outlined.

Heat-Treatment in Controlled Atmospheres. I. Jenkins. (Leeds Metallurgical Society: Iron and Coal Trades Review, 1948, vol. 156, Apr. 9, pp. 747–749). The physical chemistry of controlled-atmosphere heat-treatment processes is discussed and the production of atmospheres derived from ammonia, hydrocarbons, and charcoal is described. Finally, the selection of the most suitable controlled atmosphere for carbon and alloy steels is dealt with.—R. A. R.

Resistance Furnaces with Controlled Atmospheres. R. Henrion. (Journal du Four Electrique, 1947, vol. 56, Aug.–Oct., pp. 63–66). This is a summary of a communication made to the Groupements des Mines et de la Métallurgie de l'Ecole Centrale des Arts et Manufactures. The principles and uses of controlled-atmosphere furnaces are briefly reviewed.—R. F. F.

Nitrogen as a Carrier Gas in Gas Carburizing. W. H. Holcroft and R. P. Harris. (Metal Progress, 1948, vol. 53, Feb., pp. 241–246). The application of nitrogen as a carrier gas for methane or other hydrocarbon in gas-carburizing processes was investigated. Laboratory tests indicated that, when using nitrogen, extremely minute amounts of H_2O and CO_2 will upset the equilibrium of the furnace atmosphere. Factors to be considered when using nitrogen in full-scale installations are discussed.—R. A. R.

Large and Unique Furnaces Used in Manufacturing Propeller Blades at Hamilton-Standard Plants. (Industrial Heating, 1948, vol. 15, Jan., pp. 22–38, 170–172). An illustrated description is given of the extensive heating equipment used in the manufacture and heat-treatment of hollow stainless steel propeller blades for aircraft at the works of the Hamilton Standard Propellers division of United States Aircraft Corporation.—R. A. R.

The Development of the Heat Treatment of Mild Steel Sheets. C. G. Davies. (Proceedings of the Ebbw Vale Metallurgical Society, 1947–48, vol. 1, pp. 5–18). After defining ferrite, cementite, pearlite, and austenite, and explaining the significance of the A_1 and A_3 points, the box-annealing and normalizing of steel sheet is described in detail with micrographs of the structures obtained. A radiant-tube portable annealing furnace is also described.—R. A. R.

Commercial Heat Treating. Large Car-Type Furnaces Featured at Pearson Industrial Steel Treating Co. (Industrial Heating, 1948, vol. 15, Jan., pp. 128–130, 132, 134; Feb., pp. 310–316). The heat-treatment plant of the Pearson Industrial Steel Treating Co., Cicero, Illinois, is described and illustrated. It includes rotary-hearth, controlled atmosphere, salt-bath, hardening, and tempering furnaces, with shot-blasting and tempering equipment.—R. A. R.

The Low Temperature or "Deepfreeze" Treatment of Materials. (Pratique des Industries Mécaniques, 1946, Sept., p. 198: [Abstract]. Technique Moderne, 1947, May, 1–15, p. 184: [Abstract]. Chaleur et Industrie, 1948, vol. 29, Mar., p. 15D). Hardened steels do not acquire maximum hardness and transformations occur over a number of years resulting in a change of dimensions which make them unsuitable for certain purposes such as gauges. An account is given of low-temperature (−85° C.) treatment, which makes a steel structurally stable, and its application for hardening high-speed steels, wedges, band saws, etc.

Low Temperature Treatment and Assembly of Metallic Parts. G. B. Olson. (Machine Moderne, 1947, vol. 41, June, pp. 1–6).

Sub-Zero Treatment of High-Speed Steel. O. Svahn. (Verkstäderna, 1947, vol. 43, No. 12, pp. 263–269). [In Swedish]. A brief review is given of the fundamentals of sub-zero treatment of high-speed steel. As the consumer of high-speed tools is chiefly interested in the function of the tools, the author deals with the subject from this viewpoint and discusses the use of the treatment for improving tool performance. Investigations in the United States show improvements in tool performance up to 400%. On an average there are improvements of 20% to 30%. An account is given of some Swedish investigations. The results show the possibility of obtaining some advantages; a calculation of the costs indicates that in some circumstances the use of cold-treatment may be profitable.—J. K.

Low Temperature Treatment of Steel. H. E. Boyer. (Iron Age, 1948, vol. 161, Feb. 12, pp. 69–73, 134–135; Feb. 19, pp. 78–83; Feb. 26, pp. 85–90). The theory and practice of the low-temperature (down to −155° F.) treatment of steels are discussed. In Part I the time-temperature-transformation characteristics of the following tool steels are considered: (1) a 1% carbon steel; (2) a 1% carbon, 1·42% cobalt steel; (3) an 18/4/1 tungsten–cobalt–vanadium steel; (4) an 11·75% cobalt, 0·80% molybdenum, 0·20% vanadium steel; and (5) a 17·20% cobalt, 0·48% molybdenum steel. In Parts II and III the effect of tempering temperature on the hardness and on the volume of retained austenite in cold-treated and non-cold-treated steels are discussed. In the case of gas-carburized nickel steels and low-alloy chromium–nickel steels the hardness was substantially increased. Allowing a long time (one to four weeks) to elapse between hardening and refrigeration greatly decreases the effect of the latter and increases the amount of retained austenite. Tempering before the refrigeration also lessens the effect.—R. A. R.

Manufacture and Manipulation of Tool Steels. H. W. Pinder. (Iron and Coal Trades Review, 1947, vol. 155, July 18, pp. 113–115; Sept. 5, pp. 447–448). This is the continuation of a series of articles on tool steels (*see* Journ. I. and S.I., 1947, vol. 156, Aug., p. 578). The author discusses the use of some unconventional methods of ingot casting, including the Durville process, and the heat-treatment of tools in lead and salt baths.—C. O.

Flame Hardening. C. D. Townsend. (Steel Processing, 1948, vol. 34, Feb., pp. 71–74, 87). The flame-hardening process is described with data on the steels which are suitable for this treatment, the hardness and depth obtainable, and the cost.—R. A. R.

Surface Flame Hardening and Its Possibilities of Application to Castings. B. de Jessey. (Bulletin de l'Association Technique de Fonderie, 1944, July–Dec., pp. 33–42). After reviewing the various methods of surface hardening, the author gives an illustrated account of the spot and general surface-flame-hardening processes. The application of the process to intricate parts is briefly discussed.—J. C. R.

End Hardening of Rail Ends and Open Hearth Frogs. R. W. Torbert. (Welding Journal, 1948, vol. 27, Feb., pp. 107–110). Descriptions are given of the acetylene heating equipment and technique for hardening high carbon steel rail ends and points. The structures obtained are illustrated by micrographs.—R. A. R.

Induction Hardening Cuts Cost of Heat Treating Grass Shear Blades by 60%. (Industrial Heating, 1948, vol. 15, Feb., pp. 228–230). A brief description is given of a 10 kW. induction-hardening installation for hardening grass-cutter blades.—R. A. R.

High Frequency Hardening of Tramway Gears. I. E. Soloveitchik. (Vestnik Machinostroenia, 1947, No. 3, pp. 62–65: [Abstract]. Aperçu de la Presse Technique, 1948, vol 3, Feb., p. 8). A description of the

apparatus used and results obtained in the induction hardening of gear teeth are given.

Application of the TTT Curves in Heat Treating by Induction. H. E. Boyer. (Steel Processing, 1948, vol. 34, Jan., pp. 29–35). The suitability of certain steels for induction heat-treatment is discussed and the time-temperature-transformation curves for steels containing (*a*) manganese 1·85%, (*b*) manganese 0·94%, molybdenum 0·25%, (*c*) nickel 3·41%, (*d*) chromium 0·93%, (*e*) manganese 0·91%, molybdenum 0·25%, (*f*) manganese 0·77%, chromium 0·98%, molybdenum 0·21%, and (*g*) manganese 0·36%, silicon 0·33%, nickel 0·20%, chromium 1·41%, are presented with explanations of their application to predict the correct heating cycle for each steel.—R. A. R.

Liquid Nitriding Increases Tool Life. G. A. Roberts. (American Machinist, 1947, vol. 91, Feb. 13, pp. 134–136 : [Abstract]. Centre de Documentation Sidérurgique Bulletin Analytique, 1948, vol. 5, Jan., p. 24). Salt-bath nitriding of tools imparts great hardness and diminishes considerably the abrasive action of metal chips. The improved friction properties behind the cutting edge facilitates the formation of chips. The nitriding process is described.

Peeling of "European" or White-Heart Malleable Iron. G. Joly. (Bulletin de l'Association Technique de Fonderie, 1942, Oct.-Dec., pp. 51–55). In considering factors likely to cause peeling of castings, the author discusses the effect of the chemical composition of the metal and analyses the reactions which take place during malleablization. He examines the structure of the iron where peeling occurs and suggests that to avoid this defect, the silicon content should be kept as low as possible, though not less than 0·5%, and sulphur should be present only as manganese sulphide. The oxidizing powers of the packing material used during malleablizing should be controlled.—J. G. R.

A Comparison of Patenting Methods. Coal—Gas—Electric. (Wire Industry, 1948, vol. 15, Mar., p. 187). Coal-fired patenting furnaces are now seldom used owing to scale forming on the wire and the difficulty of uniform heating. Producer-gas-fired furnaces with air cooling is satisfactory, but where town gas is not too dear and of good quality, it is much cleaner to use and causes less damage to the furnace interior. The direct electrical-resistance method of heating the wire before it passes into the lead bath has many advantages which are enumerated.—R. A. R.

Cyclic Annealing of Alloy Steel Forgings in Salt Baths. (Industrial Heating, 1948, vol. 15, Feb., pp. 252–254). An electric salt-bath furnace and its advantages for the rapid annealing of small steel forgings, are described.—R. A. R.

Controlled Low Temperature Stress Relieving. T. W. Greene and A. A. Holzbaur. (Welding Journal, 1946, vol. 25, Mar., pp. 171-s–185-s). Welds in ship-plates can be relieved of residual stress if the plate material is stretched lengthways while the weld metal is not. In the process described, this is done by passing two 6-in. oxy-hydrogen flames, with their centres 5-in. from the centre line of the weld, along it ; the plate reaches a temperature of 176°–205° C. and the weld about 110° C. less. Water sprays follow some 6-in. behind the flame heads, which travel mechanically at 16-in./min. Examples are given of the reduction of longitudinal stresses of 40,000 lbs./sq. in. in tension in the axis of the weld, and 15,000 lbs./sq. in. in compression 6–8 in. away from it, to 3000–8000 lb./sq. in. in tension and 5000 lb./sq. in. also in tension, respectively ; similar evening-out of transverse stresses is produced.

The process has been applied to various types of weld and, not only to ships under construction, but to completed vesse's during dry-docking for repairs.—J. P. S.

Introduction to Modern Heat Treatment Practice : Isothermal Hardening. B. Hedde D'Entremont. (Machines et Métaux, 1948, vol. 32, Apr., pp. 111–115). Air hardening, isothermal hardening and stepped quenching are compared.—R. F. F.

Dual-Tempering Treatment. (Steel, 1948, vol. 122, Feb. 16, pp. 104). A furnace for simultaneously tempering gears and shafts at two different temperatures is described. The furnace is divided into two chambers by the horizontal work trays into which the gears are fitted with the shafts projecting downwards into the higher temperature zone.—R. A. R.

FORGING, STAMPING, DRAWING, AND PRESSING

Forging Practice. A. Ashburn. (American Machinist, 1947, vol. 91, May 8, pp. 117–132 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 21). A résumé is presented of current forging practice including forging of carbon steels, dies, tolerances, forging of alloy steels, high-speed steels, stainless steels, alloys with a high nickel content, copper and its alloys and aluminium and magnesium alloys.

Forging the Stainless Metals. W. Naujoks. (Steel Processing, 1947, vol. 33, Dec., pp. 735–737). Recommendations on forging techniques for stainless steel are made. These steels require longer heating and holding times to obtain uniform temperature distribution, especially for large forgings. The first few blows should be light to start the flow of metal.—R. A. R.

Forging Die Design. J. Mueller. (Steel Processing, 1948, vol. 34, Jan., pp. 17–19, 35). Descriptions are given of horizontal and vertical forming machines called "bulldozers" ; they are particularly useful for making deep bends because of the long stroke. The crank of a large machine makes 7 or 8 r.p.m., and that of small machines 50 to 60 r.p.m. The design of dies for this machine is discussed.—R. A. R.

Hot Pressing 575-Pound Propeller Hubs. F. Welshner and A. A. Flout. (Steel, 1948, vol. 122, Mar. 15, pp. 90–92, 121). Descriptions are given of the special forging machinery and processes for making hubs for four-blade propellers for aircraft of nickel–chromium–molybdenum steel.—R. A. R.

Production of Pipes from Stainless and Heat-Resisting Steel. G. P. Pishikov, G. T. Aleinichenko and N. S. Alferova. (Stal, 1948, No. 1, pp. 51–54). [In Russian]. The production of pipes from Russian stainless and heat-resisting steels is described.—S. K.

The First Ural Tube Works. Ya. P. Osadchiy. (Stal, 1948, No. 1, pp. 77–79). [In Russian]. A brief account of the achievements of the first Ural tube works since their construction started in 1930 is given.—S. K.

Examination of Ingots, Cast Billets and Seamless Tubes and of Runner Brick Used in Bottom Casting Ingots and Billets for Seamless Tube Production. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 619 (Addendum No. 2) : H.M. Stationery Office).

Tube Reducers in Germany. (British Intelligence Objectives Sub-Committee, 1948, F.I.A.T. Final Report No. 922 : H.M. Stationery Office).

Activated Lubricants for the Cold-Drawing of Tubes. V. F. Maltsev, F. M. Gertsman and M. P. Zheldak. (Stal, 1948, No. 2, pp. 147–152). [In Russian]. An account is given of investigations carried out on the

use in cold-drawing of ordinary engine oils, the lubricating properties of which had been improved by the addition of small quantities of substances, such as acidol, which contain active groups, or of paraffin, which is also known to enhance lubrication. From the results of laboratory experiments, curves were plotted to show the relation between drawing-tension and deformation for various lubricants. Full-scale tests were also made at a plant engaged in the cold-drawing of locomotive boiler tubes, and the operating data with different lubricants are compared and discussed. It was found that the use of activated lubricants enabled the number of operations required for the process to be reduced from two to one.—S. K.

The Technique of Deep Drawing as Applied to Automobile Pressings. E. N. Salmon. (Proceedings of the Ebbw Vale Metallurgical Society, 1947–48, vol. 1, pp. 32–45). The manufacture of large dies for automobile pressing, including profiling with the Keller machine, and two deep-drawing tests, namely the wedge-draw and the cup-draw tests are described in detail.—R. A. R.

Compound Tools Use Reverse Draw Technique. J. A. Grainger. (Machinist, 1947, vol. 91, Mar. 6, pp. 1493–1496). The theory of reverse drawing technique is given, together with some principles employed in the design of compound drawing tools which enable the number of operations to be reduced.—R. L. B.

The Development of the Production of Miscellaneous Articles for Industrial Use. (Stal, 1948, No. 2, pp. 99–103). [In Russian]. The development of the manufacture of wire, wire products, cold rolled strip, machine parts, etc., in the U.S.S.R. is sketched from 1864 to the present time.—S. K.

A Critical Survey of Wire-Drawing Theory. G. D. S. MacLellan. (Journal of The Iron and Steel Institute, 1948, vol. 158, Mar., pp. 347–356).

New Die Polishing Machines. (Wire Industry, 1948, vol. 15, Mar., p. 175). A description is given of a machine for polishing wire-drawing dies. A lapping method is applied, and the machine is designed to have the needle so mounted that in its working position it could only move laterally. The machine can be adjusted for using a shaped needle or to pierce a die.—R. A. R.

The Inspection and Maintenance of Diamond Wire Drawing Dies. (British Diamond Die Federation: Wire and Wire Products, 1948, vol. 23, Feb., pp. 140–143). Recommendations are made for procedures for inspecting, enlarging, and repolishing diamond wire-drawing dies.—R. A. R.

Note on a New Method for Checking the Profile of Wire-Drawing Dies. J. G. Wistreich. (Journal of the Iron and Steel Institute, 1948, vol. 158, Apr., p. 496).

Metallic Coating of Wire. H. Kenmore and F. L. Durr. (Wire and Wire Products, 1948, vol. 23, Feb., pp. 135–138). A description is given of the Kenmore process of producing steel wire coated with another metal, usually nickel. Low carbon steel rod $\frac{1}{4}$ or $\frac{5}{16}$ in. in dia. is coated with nickel by electrodeposition, and the coated rod is drawn down to the desired diameter. The process can also be applied to copper on steel and silver on copper.—R. A. R.

ROLLING-MILL PRACTICE

The Problem of the Electric Drive of Cold Rolling Mills and Recent Attempts at a Solution. R. Jung. (Métallurgie, 1948, vol. 80, Apr., pp. 25, 27, 29, 31–33). An account is given of the electrical drive and plant used with various types of cold-rolling mills, including medium strip, reversing, finishing, and tandem mills.

J. C. R.

The Calculation of Mean Reduction in Pass Rolling. I. Ya. Tarnovskii. (Stal, 1948, No. 3, pp. 232–240). [In Russian]. Two methods are at present in use for the calculation of mean reduction for pass-rolling processes resulting in unequal deformation along the width of the bar; in one, the reduction is taken to be the change in the value of the ratio of the cross-sectional area to the width; and in the other, the change in height of the corresponding rectangular section is the measure of the reduction. A theoretically better method is now proposed, based on volume-displacement, which, for the simplest case of a rectangular bar being rolled in smooth rollers, is shown to be equal to the product of the volume of the bar and the natural logarithm of the ratio of its heights before and after reduction. A generally applicable equation is deduced which shows that, for any given set of conditions, the natural logarithm of the relative reduction is equal to the integral, with respect to height, of some function of the height. Thus the application of the method to a particular case depends on the formulation and integration of the appropriate function. As an example, the case of a square-section bar being reduced in an oval pass is considered in detail; equations are worked out for the mean reduction in terms of the dimensions of the bar and pass, and of the coefficient of pass-filling; curves are given in which the mean relative reductions for ratios of width to height of pass of 1·50 to 4·00 are plotted against the ratio of the height of the section of the bar to the pass height, each curve being calculated for pass-filling coefficients of 1·0 and 0·8. The results obtained are compared with those arrived at by the two other methods of calculation, and an empirical equation is discussed. A further example of the proposed method of calculation is provided by the similar consideration of the case of a hexagonal bar being reduced in a diamond (90°) pass, a graphical aid for this type of problem being given.—S. K.

Life, Defects, and Scrapping of Rolls—General. H. Bersoux. (Iron and Steel Institute, 1948, Translation Series, No. 344). This is an English translation of a paper which appeared in Revue Universelle des Mines, 1945, Aug.–Sept., pp. 65–71 (*see* Journ. I. and S.I., 1947, vol. 157, Dec., p. 638).—R. A. R.

Modern Sheet Production. F. Platzer. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Jan.–Mar., pp. 34–42). The position of the sheet-rolling industry in Austria is briefly discussed and descriptions are then given of modern sheet-mill developments in other countries concluding with the Sendzimir mill in the United States.—R. A. R.

The Development of Continuous Hot and Cold Rolling of Flat Rolled Iron and Steel Products. S. E. Graeff. (Proceedings of the South Wales Institute of Engineers, 1948, vol. 63, Apr., pp. 159–161). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 638.

The Cold Rolling of High-Strength Strip Steels, and Their Properties. A. Pomp and W. Puzicha. (Iron and Steel Institute, 1948, Translation Series, No. 343). This is an English translation of a paper which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1943, vol. 26, No. 2, pp. 13–36 (*see* Journ I. and S.I., 1944, No. II, p. 150A).—R. A. R.

Weirton Steel Rolls Tin Plate on High Speed Mill. M. J. Wohlgemuth. (Blast Furnace and Steel Plant, 1948, vol. 36, Apr., pp. 431–433). A short illustrated description is given of the new tinplate mill of the Weirton Steel Company. It consists of five 4-high stands with 21 × 42-in. work rolls and 53 × 41-in. backing rolls. It can produce strip up to 38 in. wide at a speed of 5000 ft./min.—R. A. R.

The Cold Rolling of Stainless Tubing. Z. A. Koff. (Stal, 1948, No. 3, pp. 241–247). [In Russian]. A description is given of experiments conducted in the U.S.S.R. in 1946 with a view to improving the efficiency of the cold-rolling process for rolling of stainless steel tubing; the possibility of using the following lubricants for the process was also investigated: Animal fats, internal and suint; soap (60% fat); milk of lime with 25% by volume of supersaturated sodium chloride solution; a paste of 80% soap and 20% graphite; and silvery graphite, alone or with an equal weight of finely powdered chalk. None of these lubricants was found to be satisfacory for the passes used; details of the passes are given. The adoption of new roll calibrations, which are compared with the old, resulted in increased efficiency of the process and permitted the replacement of scarce white-lead/drying-oil lubricant by the soap-graphite paste. The new system of passes is said to be applicable to the cold rolling of all types of carbon and alloy-steel tubing.—S. K.

WELDING AND FLAME-CUTTING

Shape-Welding by the Submerged Melt Welding Process. J. A. Kratz. (American Welding Society: Steel Processing, 1948, vol. 34, Mar., pp. 141–143, 146, 147). Machines for shape-welding are described, *i.e.*, for joining pieces such that the direction of the weld changes. All the machines operate the submerged-arc or Unionmelt process and magnetic synchronizers and other devices are used to make the welding head follow the contour of a template. An example of a weld changing direction in more than one plane is the welding of a manhole ring on to a cylindrical boiler.—R. A. R.

The Welding of Stainless Steel. D. A. J. Nolen. (Lastechniek, 1948, vol. 4, Apr., pp. 47–51). [In Dutch].

High Hardenability Steels Salvaged by Welding. H. J. Nichols. (American Foundryman, 1948, vol. 13, Mar., pp. 46–47). Grinding the lugs of cast-steel tank shoes (C 0·45–0·53%, Mn 1·30–1·55%, Si 0·35–0·60%, Cr 0·45–0·60%, Mo 0·35–0·45%), produced overheating followed by self-quenching and cracking. To salvage 20,000 castings so produced, the procedure was adopted of flame-cutting the cracked material away and building up with NRC 2A electrodes (composition not stated) which generate an arc atmosphere low in hydrogen. After tempering for 1 hr. at 1225° F. (660° C.) both the welds and the heat-affected zones were within the specified hardness range. In the final inspection 96·78% of the salvaged parts were passed.—J. P. S.

Welding and Fabrication of High-Temperature Alloys. C. G. Chisholm. (Journal of the American Welding Society, 1948, vol. 27, Mar., pp. 217–222). The welding is described of high-temperature alloys, such as Haynes Stellite Alloys Nos. 21, 23, 27, 30 and 31 (cobalt or cobalt–nickel base), Hastelloy alloys B and C (nickel-base alloys with tungsten or molybdenum), Multimet alloy (cobalt–nickel–iron base), and stainless steels such as 18/8 modified with niobium or titanium. The weldability of these alloys is comparable with that of austenitic stainless steel, and, generally the same techniques may be employed. In welding assemblies for turbo-superchargers and jet engines from fabricated sheets, from sheets joined to precision-cast parts, and from precision-cast parts joined to forgings, metallic arc, Heliarc, atomic hydrogen, and Unionmelt submerged-arc processes are used.—J. P. S.

Arc Welding Stainless Impellers. W. L. Elliott and G. Handyside. (Steel, 1948, vol. 122, Apr. 12, pp. 82–84). The technique for arc welding in the fabrication of large stainless-steel impellers is described; particular attention is given to methods of preventing distortion.

New High Alloy Hardfacing Materials Adapted to Automatic Arc Welding. (Materials and Methods, 1948, vol. 27, Mar., pp. 78–79). Filler rods for hard-alloy facing are now made in tubular form with the alloying elements in granular form inside them. Various compositions are quoted, suitable for open- or submerged-arc welding. The rods are suitable for use in automatic welding machines if care is taken that pressure from the feed rolls is positive but not excessive.—J. P. S.

Structural Strength of the Welded Joint. G. S. Mikhalapov. (Adams Lecture: Welding Journal, 1948, vol. 27, Mar., pp. 193–206). The author points out that all except the simplest structures are called upon to withstand triaxial stresses and that therefore knowledge of the behaviour of the materials under uniaxial stress is seldom sufficient to predict performance under service conditions. Certain new parameters of service conditions have come to light during the war, notably high rate of strain, steep strain gradient, and low temperature; these appear to be to some extent interrelated. Experiments on the design and methods of construction of welded steel ships have shown considerable variation in susceptibility to notch sensitiveness of various steels; the transition temperature, below which notch sensitivity rises rapidly, varying considerably as between different batches of semi-killed steels and between the best of these and a fully killed normalized steel. However, in full-scale tests on portions of welded structures, relatively random changes in welding procedures have produced more benefit than planned improvements in the steel.

Arising from the war-time necessity of studying the effects of localized impact on welded joints, an investigation was carried out in which small charges of explosive were detonated on plates both welded and unwelded, as a means of applying a controllable impact. It is found that each composition of steel possesses a critical velocity of impact, above which the plate fails by spalling at the back and below which it fails by fracture normal to the plane of the component parts of the joint. A remarkable difference between the modes of failure of notch-resistant and notch-sensitive plates tested below this critical velocity is shown in that the former fail by means of a single or a Y-shaped crack, the latter by shattering into many pieces. In the case of welded joints in similar steels, the notch-resistant steels fail through the weld and the notch-sensitive steels by general shattering. In the case of a steel moderately notch resistant, failure is by shattering in a welded plate and by cracking in an unwelded one.—J. P. S.

Resistance Welding in Mass Production. A. J. Hipperson and T. Watson. (Australasian Engineer, 1948, Feb. 7, pp. 65–67). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 403.

Welding at Low Temperatures. B. I. Madovar and A. E. Asnis. (Avtogennoe Delo, 1947, No. 12, pp. 15–17 [in Russian]. [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 10). Methods to adopt for welding at temperatures of − 40° to − 50° are outlined.

The Relationship of Inspection to Welding. C. W. Brett. (Engineering Inspection, 1948, vol. 12, Spring Issue, pp. 4–6). Recommendations are made on the inspection of welds.—R. A. R.

The Metallurgical Laboratories of the B.W.R.A. J. G. Ball. (Welding, 1948, vol. 16, Mar., pp. 106–112). The organization and equipment of the laboratories of the British Welding Research Association are described with notes on the present research programme.—R. A. R.

Brazing of Iron Castings with a Hard Metal, N. P. Nikitine. (Avtogennoe Delo, 1948, No. 1, p. 31 [in Russian]. [Abstract]. Aperçu de la Presse Technique,

1948, vol. 3, Apr., p. 11). A process for the repair of iron castings is outlined.

Soft Soldering the "Difficult" Metals. D. F. Hewitt. (Practical Engineering, 1948, vol. 17, Feb. 13, pp. 114–115: Z.D.A. Abstracts, 1948, vol. 6, Mar., p. 43). Some practical notes are given on methods which may be used for soft-soldering cast iron, aluminium, aluminium bronze, zinc alloy die castings and stainless steels. In many cases the soldered joints are much weaker than the original metal, so it is advisable to restrict such repairs to lightly stressed parts.

Powder Cutting as a Production Tool. D. H. Fleming. (Welding Journal, 1948, vol. 27, Mar., pp. 181–187). Powder-cutting of stainless-steel consists of introducing a finely divided iron-rich powder into the cutting oxygen stream; the additional heat of the burning powder and the fluxing action of the superheated particles keeps the refractory oxides of the elements in the steel in a molten condition and enables them to be ejected in the slag stream. The costs of the process are shown to be lower than those of conventional shaping processes, and by judicious lay-out the maximum area of the plate can be used. By progressive quenching on thin sections the danger of carbide precipitation in unstabilized alloys can be avoided, and in general the effects of the heating are no worse than those of unquenched welding. J. P. S.

The Powder Process in Stainless Steel Production. C. J. Burch and E. M. Holub. (Association of Iron and Steel Engineers: Blast Furnace and Steel Plant, 1948, vol. 36, Apr., pp. 443–446). The equipment and technique for oxy-acetylene cutting stainless steel by injecting a fluxing powder into the oxygen stream is described. Data on gas consumptions, cutting speeds, and costs are given. Powder-scarfing of ingots and slabs is claimed to yield a better product than grinding.—R. A. R.

Oxyacetylene Production Cutting in Steel Mills. A. H. Yoch and W. Begerow. (Welding Journal, 1948, vol. 27, Mar., pp. 188–192). This paper describes the use of single and multiple torches for (*a*) the hot cutting of blooms and billets of carbon and alloy steels and (*b*) cold-cutting of shapes from plates, slabs, and forgings, and of stock into lengths for other operations.—J. P. S.

MACHINING AND MACHINABILITY

Progress Report No. 1 on Tool-Chip Interface Temperatures. K. J. Trigger. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Feb., pp. 91–98). Changes in tool-chip interface temperature with machining conditions were measured using the Herbert-Gottwein thermocouple of which the work-piece is one member and the cemented carbide the other member. At a feed of 0·01 in./rev. and other factors kept constant, the cutting temperature increases with increase in depth of cut up to 0·100-in. depth and is relatively unaffected as the depth is increased to 0·150 in.—R. A. R.

The Machinability of Lead-Bearing Steels. H. Schrader and H. Schallbroch. (Technik, 1948, vol. 3, Mar., pp. 97–104, 122). Data are presented on the effect of additions of about 0·2% of lead on the machinability and mechanical properties of eight alloy steels. The machinability was in all cases improved, whilst the tensile strength, toughness, ageing properties, fatigue strength, hardness, and strength in the hot state remained unchanged or were very slightly affected by the lead. Methods of testing the machinability are described. The lead has a lubricating action which reduces the friction between tool and work, and the exceedingly fine distribution of the lead as a result of the condensation of the metal vapour, together with the reduction of the strength of the chips at high temperature, cause the chips to break up in very small pieces.—R. A. R.

Evolution of Technique of Machining Metals. J. Jacquet. (Bulletin Technique Veritas, 1947, Nov., pp. 141–146; Dec., pp. 165–172. [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 7). An account is given of progress in the study of the constitution of steels, the influence of alloying elements on cutting properties, heat-treatments, economy in the consumption of high-speed steels and comparison of cutting conditions.

Water-Mixed Cutting Fluids. W. H. Oldacre. (A.S.T.M. Symposium on Cutting Oils: A.S.T.M. Bulletin, 1948, No. 151, Mar., pp. 45–46). This deals with the history of cutting fluids, leading to the present use of emulsions of oil, soaps, and water. It is concluded that there exists a need for an accurate and careful survey of practice and a comprehensive study of the theory of metal cutting.—J. P. S.

Cutting Fluids. E. A. Reehl. (A.S.T.M. Symposium on Cutting Oils: A.S.T.M. Bulletin, 1948, No. 151, Mar., pp. 47–48). This paper deals with water-soluble cutting fluids and discusses the suitability for various applications of (*a*) straight mineral oils, (*b*) sulphurized mineral oils, (*c*) sulphur-chlorinated mineral oils, (*d*) sulphurized fatty or vegetable oils, and (*e*) sulphur-chlorinated fatty or vegetable oils.—J. P. S.

Correlation of Laboratory Testing of Cutting Fluids with Field Tests. D. J. Wangelin. (A.S.T.M. Symposium on Cutting Oils: A.S.T.M. Bulletin, 1948, No. 151, Mar., pp. 48–49). Both field tests by actual cutting of materials in the workshop under standardized conditions, and laboratory tests where chemical analysis and determination of physical properties are combined with metal cutting tests, can be of value in the study of cutting fluids. To correlate these tests requires a clear understanding of the mechanics of metal cutting and of the action of a cutting fluid in various types of machining operation. No theory of the action of cutting fluids is yet accepted by the metal-cutting industry.—J. P. S.

Carbide Inserts for Single Point Tools. T. E. Lloyd. (Iron Age, 1947, vol. 161, Apr. 15, pp. 82–83). A new design of carbide-tipped tool is described in which the carbide insert is mechanically clamped instead of being brazed or welded. In one type the insert is round so that on loosening the clamping screws it can be turned round, moved forward, and then ground; the tool can thus be reground many times before being discarded. R. A. R.

POWDER METALLURGY

Powder Metallurgy—Its Widening Sphere of Usefulness. C. G. Goetzel. (Engineers' Digest (N.Y.), 1948, vol. 5, Mar.–Apr., p. 96). Future prospects for powder metallurgy are briefly discussed.—R. F. F.

The Powder Metallurgy of Porous Metals and Alloys Having a Controlled Porosity. P. Duwez and H. E. Martens. (American Institute of Mining and Metallurgical Engineers: Technical Publication No. 2343: Metals Technology, 1948, vol. 15, Apr.). A new approach to the problem of cooling parts exposed to high temperatures is through the method of making them of a porous material and passing the cooling liquid through in a direction opposite to that of the heat flow. The coolant eventually forms a protective layer on the surface exposed to heat. This method is known as "sweat cooling." To obtain compacts of the desired permeability the metal powders were mixed with − 80 mesh ammonium bicarbonate, while surrounded by dry ice: the low temperature is required to prevent premature dissociation of the salt. The amount added was between 3%

and 17% of the total weight, according to the degree of porosity required. A number of compacting pressures were used, from 40,000 to 100,000 lb./sq. in. It was found that both increased ammonium bicarbonate content and reduced compacting pressure increase the porosity, and that the higher the ammonium bicarbonate content, the less is the effect of increased pressure upon the porosity. Study of the mechanism of sintering carried out during this investigation has shown that study of the thermal expansion curve of the compact is of great value. The maximum found on such curves indicates the minimum temperature below which sintering will not take place, and in the case of complex mixtures, the critical range through which the rate of rise of temperature should be reduced to avoid distortion. J. P. S.

The Problem of Testing and Evaluating the Mechanical Properties of Powder Metallurgy Products. W. Jung-König and G. Wassermann. (Metallforschung, 1947, vol. 2, July–Aug., pp. 244–249). It is recommended that the hardness of parts made from iron powders by powder metallurgy should be determined directly from the depth of the impression left by the Brinell ball, not from the diameter. Tensile tests on bars as-pressed and on bars machined out of larger pieces showed little difference provided that the machining was carefully done. Impact-bend tests on as-pressed specimens $10 \times 10 \times 55$ mm. without any notches are recommended for determining impact resistance ; machined specimens should be smaller, *e.g.*, $4 \times 4 \times 27$ mm.—R. A. R.

PROPERTIES AND TESTS

Statistical Aspect of Fracture Problems. B. Epstein. (Journal of Applied Physics, 1948, vol. 19, Feb., pp. pp. 140–147). In recent years there has been an increasing interest in the development of statistical theories of strength. The main aim of these theories is to explain in a reasonable way such things as the dependence of the strength of specimens on their volume or length. In this paper it is pointed out that the problems posed by these models are equivalent to an important problem in mathematical statistics, namely, the distribution of the smallest value in samples of size n drawn from a population having some probability density function $f(x)$. The calculations made by mathematical statisticians give a far more complete description of the results to be expected than do the estimates to be found up to now in the technical literature.

The Determination of Elastic Constants. J. R. Wuolijoki. (Teknisk Tidskrift, 1948, vol. 78, Apr. 17, pp. 251–252). [In Swedish]. The calculation of the elastic and shear moduli of a beam subjected to alternating bend stress is explained.—R. A. R.

Dilatometry. N. A. McKinnon. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy, Part 4, Physical Apparatus for Metallurgical Measurements, 1947, Sept.). A survey is made of methods of dilatometric analysis, special emphasis being given to methods using the dial gauge, optical lever, and parallel plate condenser. The author believes that the dial gauge fitted with an automatic recorder offers the best solution to the problem of a general purpose dilatometer. The speed of response of the parallel-plate-condenser apparatus is so high that it can be used to study transformations at very high rates of cooling and, with the more recent developments of electronics, the stability is such that it also finds application for measuring slow changes of dimensions.

On the Upper Yield Point: Its Occurrence in Bending Tests and Its Explanation. C. Benedicks and R. Skorski. (Arkiv för Matematik, Astronomi och Fysik, 1947, vol. 34A, No. 20). Experiments proving the existence of an upper yield point in bend tests are described. It is pronounced when a hard constituent is present in the grain boundaries. This constituent is probably an oxide since, on annealing in a reducing atmosphere, the upper and lower yield points merge into one.—R. A. R.

New Methods of Testing in the Finishing of Sheet Metal. F. Eisenkolb. (Technik, 1948, vol. 3, Feb., pp. 62–66). New methods of testing rods and sheet metal are described. Details of the twisting test have already been given (*see* Journ. I. and S.I., 1948, vol. 159, May, p. 100). The other tests include : (*a*) A cold bend test in which a flat strip is pressed by a prism into a V-shaped die and the side in tension is examined for cracks ; (*b*) a cold rolling test in which the specimen is rolled while in tension ; (*c*) a weldability test in which impressions are made along the centre line of a weld ; and (*d*) a weld-crack sensitivity test in which a butt weld is made between the ends of two firmly clamped strips of the sheet metal to see whether cracks form on contraction. —R. A. R.

The Design of Steel Columns in Compression. S. G. Bergström. (Teknisk Tidskrift, 1948, vol. 78, Apr. 24, pp. 261–263). [In Swedish]. Some disadvantages of present methods of designing steel columns and determining safety factors are pointed out, and a new method of making these calculations based on compression and simultaneous bending is explained.—R. A. R.

The Correlation of Laboratory Tests with Full-Scale Ship Plate Fracture Tests. E. P. Klier, F. C. Wagner, and M. Gensamer. (Welding Journal, 1948, vol. 27, Feb., pp. 71-s–96-s). In this report the notch impact tests conducted on merchant-vessel-quality ship plate are discussed. Tests have been conducted so as to establish the energy-absorption/temperature curves for selected steels having widely separated temperatures of transition from ductile to brittle failure. A special test-piece was developed for predicting the behaviour of large plates in bending. —R. A. R.

The Fundamentals of the Applied Plastic Shaping of Metals. W. Engelhardt. (Technik, 1948, vol. 3, Feb., pp. 57–61). The author points out that although stress-strain relationships for metals within the elastic range are known with some exactitude, the problems of plastic deformation are not yet susceptible to equally rigid mathematical analysis. He then reviews the work of various investigators on the mechanism of plastic deformation of single crystals and polycrystalline aggregates, particularly with reference to deep drawing, and concludes that the two important basic quantities are the resistance of the undeformed metal to plastic deformation, and the increase in this resistance with the amount of work done on the metal. —M. A. V.

Development of Modern Theories on the Plasticity of Metals. P. Laurent. (Revue Universelle des Mines, 1948, Series 9, vol. 4, Mar., pp. 221–230). The theories on plasticity of metals are reviewed under two headings : plastic deformation of single crystals and plastic deformation of polycrystals. A new theory is suggested, namely, that the interaction of the individual crystals making up the polycrystal takes part in the mechanism of deformation.—R. F. F.

Stress Analysis Utilization in Dynamic Testing. R. W. Brown. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 4, No. 2, pp. 42–51). A description is given of apparatus incorporating a direct-current bridge balance and oscillograph circuit for the dynamic measurement of displacement, velocity, acceleration, and stress. Its application for analysing the

stresses in an aircraft undercarriage is shown.—R. A. R.

The Propagation of Plastic Deformation in Metals. P. Duwez. (Publications de l'Association des Ingénieurs de la Faculté Polytechnique de Mons, 1947, vol. 95, No. 4, pp. 1–8). A review is presented of the principles of the theory of the propagation of plastic deformation in metals and an account is given of experiments which illustrate these principles.—J. C. R.

Influence of a Deformation on the Thermo-E.M.F. of Metals. C. Crussard and F. Aubertin. (Comptes Rendus, 1948, vol. 226, Jan. 5, pp. 75–76). Experiments were carried out on copper, aluminium, iron, and nickel wires to study variations that occur in the thermo-E.M.F. when the metal is deformed. In the case of iron, elastic torsion affected the thermo-E.M.F. considerably ; plastic deformation had a considerable and irregular effect with a change of sign.—J. C. R.

X-Ray Stress Measurements on Steels of Different Carbon Contents and Different Microstructures. F. Bollenrath and V. Hauk. (Metallforschung, 1946, vol. 1, Dec., pp. 161–167). X-ray stress determinations were carried out on specimens of three carbon steels (carbon 0·11%, 0·76%, and 1·12%) during bend tests, using cobalt and chromium-Kα_1 rays from different directions. Different values of the elastic moduli were obtained for the individual specimens, structures, rays, and directions. It is concluded that with steels the effect of anisotropy is not so simple as was previously thought. The method proposed by H. Neerfeld for calculating the X-ray elastic coefficient is, however, valid for heat-treated steels of medium carbon contents.—R. A. R.

The German Part in the Development and Application during the War of the X-Ray Method of Determining Elastic Stresses. H. Neerfeld. (Kaiser-Wilhelm-Institut für Eisenforschung : Stahl und Eisen, 1948, vol. 68, Mar. 25, pp. 127–128). A brief report is presented on X-ray stress determinations during tensile and fatigue tests on flat specimens with notches of different dimensions. The local concentrations of stress (above the elastic limit) do not necessarily mean that there is danger of fracture as the plastic deformation relieves the stress.—R. A. R.

Measurement of Stress by Means of X-Rays. D. E. Thomas. (Journal of Applied Physics, 1948, vol. 19, Feb., pp. 190–193). The article shows how the formulæ used in stress measurement by X-rays are derived and points out an error in the recently published book " X-Rays in Practice," by W. T. Sproull. The techniques of measuring stress in back-reflection photographs, either by one exposure at 30° or 45° incidence, or by two exposures at normal incidence, are discussed. —R. A. R.

The Measurement of Strain. J. H. Lamble and S. S. Gill. (Transactions of the Liverpool Engineering Society, 1947, vol. 68, pp. 3–37). After explaining circles of stress and strain and the equations for calculating the principal stresses in a two-dimensional stress system, the authors give details of the principal types of extensometers and strain-measuring devices in use, with information on their calibration, accuracy, and sensitivity.—R. A. R.

The Use of Electric Resistance Wire Strain Gauges in Static Strain Measurements. W. H. Wittrick. (Journal of the Institution of Engineers, Australia, 1947, vol. 19, Aug., pp. 165–172). This paper presents a general account of electrical resistance strain gauges and the instrumentation required for their application to static strain measurement. The first portion deals with the basic principle underlying their operation and the installation of the gauges on the test specimen. Later, various types of measuring instruments are described and their relative merits discussed. Finally, a description is given of how shear strain may be measured by means of this type of gauge.—R. A. R.

A Quasi Non-Destructive Method of Determining Residual Stresses. W. Soete and R. Van Crombrugge. (Revue de la Soudure/Laschtijdschrift, 1947, vol. 3, No. 4, pp. 161–174). [In Flemish]. A mathematical justification of the three-strain-gauge method of determining residual stresses (*see* next abstract) is presented.—R. A. R.

The Measurement of Residual Stress in Depth. W. Soete and R. Van Crombrugge. (Revue de la Soudure/Laschtijdschrift, 1948, vol. 4, No. 1, pp. 17–28). [In Flemish.] A method, using three resistance strain gauges, for determining residual stress below the surface of a steel plate is described. The gauges are placed radially on the surface of the plate and the changes in strain are noted as a hole is drilled at the focal point. A relationship between these changes and the depth of the hole is established.—R. A. R.

Residual Stresses in Rolled Strip. Ya. S. Gallai, M. I. Zlotnikov, and N. N. Sokolovski. (Stal, 1948, No. 1, pp. 37–45). [In Russian]. The method of Heyn and Bauer was used to determine the residual stresses in thin strip made by flattening wires of various steels with diameters from 0·75 to 12 mm. After considering the distribution of residual stresses in a strip, the relationship of these stresses to the various factors entering into the production of the strip is dealt with. The following conclusions are drawn : The maximum values of tensile stresses are always greater than those of compression stresses, and the distribution of residual stresses in a cross-section of strip is almost independent of the nature of the wire or of the conditions of flattening, these factors only influencing the magnitude of the stresses ; for steel the residual extension stress in tension is 20–30 kg./sq.mm. ; increased reduction results in increased residual stress and tensile strength and in decreased specific elongation ; the residual stress and tensile strength increase and the specific elongation decreases with decrease in the number of passes ; the use of annealed wire results in greater residual stress ; the residual stress increases with diminution of the diameter of the wire or of the roll, or if the wire is under tension ; and lubrication of the surfaces of contact during rolling decreases the residual stress.—S. K.

Fatigue Strength and Notch Factors of Unalloyed and Alloyed Steels at + 20° and − 78°. A. Pomp and M. Hempel. (Kaiser-Wilhelm-Institut für Eisenforschung : [Abstract]. Stahl und Eisen, 1948, vol. 68, Jan. 1, p. 25). Compressive-tensile fatigue tests and impact and hardness tests were carried out on plain carbon and alloy steels at + 20° and − 78° C. The reduction in temperature raised the elastic limit, tensile strength, and hardness, but did not reduce the fatigue strength of unnotched and notched specimens. The limit of loading under the same number of stress reversals was higher for unnotched specimens at the lower temperature and practically the same for notched specimens.—R. A. R.

The Hardening of Steel during Cold-Working and Ageing. V. K. Tselikov. (Stal, 1948, No. 2, pp. 157–159). [In Russian]. A brief description is given of experiments carried out on specimens of Bessemer steel rails to determine the effects of cold-working and heat-treatment on the hardness, resistance to wear, and corrosion by sulphuric acid of this type of steel. It was found that preliminary cold-working followed by heating at temperatures above 250–300° C. resulted in a considerable increase in resistance to wear.—S. K.

Prestressing and Surface Hardening of Steel Pieces. J. Pomey. (Régie Nationale des Usines Renault, Pamphlet, May 6, 1947). The purpose of this review is to show how the ill-effects of residual quenching stresses may be counteracted by the condition of prestressing produced by superficial hardening treatments. The development of compressive stresses in the hardened layers diminishes their brittleness and the sensitivity to notches due either to the design of the part or to microgeometric irregularities of the surface. This state of compression raises the hardness, the endurance under flexural or torsional alternating stresses and the corrosion-fatigue resistance. The equilibrium of the stresses calls forth a state of tension in the substratum below the hardened layer and precautions must be taken to prevent any ill-effects from this.

The first Section of this review discusses generally the theory of stresses, what happens when stresses are applied to metals under various conditions (including the hardening effect), the influence of the shape of the piece, and methods of measuring interval stresses. The second Section deals with the internal stresses set up by various heat-treatments and their effects on the properties of the material, and the third Section is similarly concerned with case-hardening and nitriding. In the fourth Section attention is given to mechanical methods of surface prestressing (work-hardening, autofrettage, "cloud bursting," and burnishing). A lengthy bibliography is appended.—A. E. C.

Selecting Automotive Steels. W. E. Jominy. (Society of Automotive Engineers: Steel, 1948, vol. 122, Mar. 8, pp. 82–86, 122, 124). The manner in which tensile, impact, and hardenability test data can be applied to assist in the selection of steels for particular purposes is discussed.—R. A. R.

Solubility Determinations by Means of Microhardness Testing. H. Bückle. (Metallforschung, 1946, vol. 1, July–Aug., pp. 43–47). A technique is described for determining the solubility of one metal in another by making microhardness determinations. Examples are given relating to the solubilities of beryllium, titanium, and thorium in aluminium.—R. A. R.

The Effect of Surface Conditions in Hardness Measurements. P. Bastien and A. Popoff. (Iron and Coal Trades Review, 1948, vol. 156, Mar. 19, pp. 579–586). This is a translation of a paper which appeared in Revue de Métallurgie, 1945, vol. 42, Dec., pp. 373–388 (*see* Journ. I. and S.I., 1947, vol. 156, Aug., p. 585).—R. A. R.

Effects of Grinding on Physical Properties of Hardened Steel Parts. H. E. Boyer. (Steel Processing, 1947, vol. 33, Dec., pp. 738–741, 760). Tests were made on specimens of chromium steel hardened to Rockwell C 63–65 to study the effect of grinding on the mechanical properties. The conclusions were: (1) Even the most careful grinding induces tension stresses in the ground surfaces of through-hardened steel parts, thus disturbing the stress balance; (2) austenitizing temperature has a marked influence on the stress condition induced by grinding because of the structural change from the heat generated in grinding; (3) impact tests prove that the shock resistance of a hardened steel part is decreased by grinding; (4) the fatigue resistance of highly hardened steel parts is lowered by grinding.—R. A. R.

Factors Influencing the Weldability of High Tensile Alloy Steels, and a New Weld Cracking Test. P. L. J. Leder. (Institution of Mechanical Engineers, 1948, Advance Copy). The paper consists of a short review of the factors controlling the weldability of steel, together with an account of certain work carried out in connection with the welding of armour-type steel. After referring to the basic principles governing the weldability of steel, and describing the influences of alloying additions, the paper discusses the problems peculiar to deep-hardening steels, and summarizes current views on the causes of hardened-zone cracking. A detailed description is given of an improved welding test, and of some of the work carried out with it. In this test the test plates are mounted in a calibrated jig which restrains their movement due to welding stresses in two directions, and which by its own deflection, provides a measure of the forces exerted on it by the welded test plates. Results obtained with this appliance are related to the theories put forward.

R. A. R.

The Influence of the Composition of a Steel on its Mechanical Properties. B. Hedde D'Entremont. (Machines et Métaux, 1948, vol. 32, Mar., pp. 103–106). Algebraic formulæ for calculating hardenability are compared and the Jominy test is discussed. The Timken "Hardenability Calculator" is described: the construction of this instrument is based on Grossman's curves. —R. F. F.

Age Hardening of Metals. K. Honda. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1593: H.M. Stationery Office).

The Measurement of the Magnetic Properties of Fine Wire. P. T. Hobson, E. S. Chatt, and W. P. Osmond. (Electronic Engineering, 1947, vol. 19, Dec., pp. 383–387). An apparatus is described for measuring the remanence and coercivity of wires 0·004 in. in dia., with a maximum applied field of 1000 oersteds, and with a sensitivity sufficient to measure remanence down to 100 gauss. The method is based on the use of a cathode-ray oscilloscope for displaying B-H curves.—R. A. R.

New High Permeability Magnetic Material Developed in Japan. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./241: H.M. Stationery Office). Particulars are given of a high-permeability magnetic iron–aluminium alloy (14–16% of aluminium) developed at the Tohoku Imperial University. Two appendices contain English summaries of papers by H. Masumoto and H. Saito on the magnetic properties and heat-treatment of iron–aluminium alloys. —R. A. R.

Ferromagnetic Structure of Cold-Worked Austenitic Stainless Steels. P. T. Hobson and W. P. Osmond. (Nature, 1948, vol. 161, Apr. 10, pp. 562–563). Austenitic stainless steel has been rendered ferromagnetic by drawing into fine wire and this wire is used for the recording of music. Intrinsic coercivities as high as 500 oersteds have been obtained by suitable heat-treatment after drawing. The authors put forward calculations which support the theory that the material consists of a dispersion of ferrite particles, probably long in relation to their cross-section, and of individual volumes of the order of a single domain, in a non-magnetic matrix of austenite.—R. A. R.

Static Study of Magnetostriction in Austenitic Iron–Nickel Alloys. H. Devèze. (Comptes Rendus, 1948, vol. 226, Mar. 1, pp. 727–729). The magnetostriction of austenitic iron–nickel alloys, where the nickel content varied from 36% to 100%, was studied by examining the relationship between the induction B of the specimen and the corresponding variation in length $\Delta l/l_0$. Curves are plotted relating $\Delta l/l_0$ with B and $d(\Delta l/l_0)/dB$ with the percentage of nickel in the alloy. The latter shows a maximum at about 47% of nickel.—J. C. R.

Magnetic Properties of Generator Rotators as Affected by Composition. G. S. Downing, W. E. Jones, and L. E. Osman. (Metal Progress, 1948, vol. 53, Jan., pp. 87–91; Feb., pp. 235–240). Results of laboratory tests on the magnetic properties of generator-rotor forgings of

vanadium steel after various forms of heat-treatment are presented and related to their mechanical properties ; the influence of the microstructure and deoxidation practice is also examined.—R. A. R.

Non-Destructive Testing of Metals. P. Sutter. (Journal de la Société des Ingénieurs de l'Automobile, 1947, vol. 20, Feb., pp. 35–44 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 38). Optical, acoustic, physical, chemical, electric, magnetic, and electromagnetic methods of testing metals are reviewed.

Non-Destructive Methods for Testing Materials. M. Serrado. (Pratique des Industries Mécaniques, 1947, Nov., pp. 331–339 : [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Mar., p. 2). Supersonic methods do not so much compete with as supplement micromagnetic and radiographic methods of testing, each of which has its own field of application. Supersonic methods are incapable of detecting surface defects, which the magnetoscope would reveal, but they can penetrate into steel several metres in depth beyond the range of X-rays. The latter, however, give results that are easier to interpret.

Automatic Measurement of Sheet Metal Thickness by X-Rays. H. Seymour. (Petroleum, 1947, vol. 10, Mar., pp. 68–69).

Characteristics of Some Non-Screen Films Used in Industrial Radiology. R. L. Durant. (Journal of Scientific Instruments, 1948, vol. 25, Mar., pp. 105–110). An investigation has been made of the characteristics of selected X-ray films suitable for use with metal intensifying screens, with particular reference to their variation with time of development. The results show that a much wider range of film speed and contrast can be obtained. In extreme cases speed ratios of 400 : 1, and contrast ratios of 5 : 1 are obtainable by modification of the time of development alone. Applications of this technique to practical radiography are considered both for obtaining maximum contrast and for matching the density range of the film to the range of thickness in the specimen under examination. The variation of development technique as an alternative to variation of tube voltage is discussed and it is pointed out that the former is more useful for voltages above 200 kV., whereas the latter is of more importance at lower voltages.

A Comparison of X-Ray and Gamma-Ray Methods for Testing Steel Castings. (Foundry Trade Journal, 1948, vol. 84, Mar. 18, p. 270). The Non-Destructive Testing Sub-Committee of the Steel Castings Division of the British Iron and Steel Research Association has published information to act as a guide to prospective users of radiographic equipment. The advantages of the two processes are given, together with data on the cost of equipment and operation.—R. A. R.

Precision Radiography at Two-Million Volts. E. A. Burrill. (Non-Destructive Testing, 1947, vol. 6, Autumn pp. 42–47, 51). The main features of the 2,000,000-V. X-ray equipment at the Massachusetts Institute of Technology are described and examples of both production and precision radiography with it are given, including stereoscopic and stroboscopic radiography.—R. A. R.

The Value of High Voltage X-Ray in Automotive Parts. E. H. Grimm. (Non-Destructive Testing, 1947, vol. 6, Autumn, pp. 20–21). The advantages obtained by using X-rays in a foundry producing cast steel crankshafts, malleable iron castings, and hydraulic jacks are described.—R. A. R.

Short Source-Object-Distance Exposure Techniques in Spotweld Radiography. R. C. McMaster, F. C. Lindvall, and J. W. Smith. (Non-Destructive Testing, 1947, vol. 6, Autumn, pp. 31–37).

The Optical System of Polariscopes as Used in Photoelasticity. C. Mylonas. (Journal of Scientific Instruments, 1948, vol. 25, Mar., pp. 77–81). This paper describes the investigation carried out for the construction of the new polariscope at University College, London. The uniformity of illumination of the optical field and the sharpness of the isochromatics are two indispensable conditions for a good polariscope. Their fulfilment depends on the size of the light source, on the sizes, focal lengths, and respective positions of the condenser, collector and camera lenses, and finally on the thickness of the specimen. The necessary relations between these factors are determined and may be applied in choosing the components of a polariscope according to its intended use. Finally a discussion on the need for a strongly illuminated field, as well as of a sharp image, shows that a compact and intense source is needed.

Applications of the Magnetic Oscillograph. R. H. Cole. (Iron Age, 1948, vol. 161, Feb. 26, pp. 74–77). Examples of metallurgical applications of the magnetic oscillograph are described. In one instance it was used to obtain a record of the changes in strain of a punch shank during the punching of a hole ; in another it was used to discover that electric motor bearings wear rough and cause intermittent high voltage loss in the motors ; in a third, speed-torque curves were calculated from a time-speed oscillogram.—R. A. R.

Inspection Methods Using Magnaflux and Zyglo in Production Industries. W. E. Thomas. (Non-Destructive Testing, 1947, vol. 6, Autumn, pp. 9–14). The magnetic-powder and fluorescent-penetration methods of detecting defects in steel are described with examples, and their economic aspects are discussed.—R. A. R.

Interpretation of the Coefficient of Viscosity of Metals. Ya. Oding. (Izvestia Akademia Nauk, U.S.S.R., 1947, No. 12, pp. 1713–1719 : [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Mar., p. 1). The influence of viscosity in the plastic deformation of metals is examined and its relation to other properties of steel is noted.

The Determination of Powder Density Using the Rees-Hugill Flask. A. H. B. Cross. (Transactions of the British Ceramic Society, 1948, vol. 47, Jan., pp. 38–52). The paper reviews a series of powder-density results obtained by the direct-reading method using a Rees-Hugill flask, a modified burette method, and those obtained using a specific gravity bottle. A difference between the direct-reading and burette results suggested calibration errors in the Rees-Hugill flask which were confirmed. Suitable corrections were applied, but whilst these eliminated the differences between the two methods, there still remained a range (up to 0·030) between triplicate determinations on the same sample. This was shown to be due to temperature changes during the experiment, a change of 1° C. affecting the powder density result to the extent of 0·016. Further corrections were applied and the final result (" Corrected Rees-Hugill ") was in 23 out of 25 cases within ± 0·003 of the specific gravity bottle result.

Work Carried out during the 1914–1918 War on Semi-Steel Shells, Particularly the 155. A. Brizon. (Bulletin de l'Association Technique de Fonderie, 1940, Mar.–Apr., pp. 39–46). A review is presented of investigations carried out during the 1914–1918 war on semi-steel shells, with particular reference to the sound produced when struck with a hammer, and to hardness and firing tests.—J. C. R.

Microradiography. Y. Verwilst. (Prévention des Accidents et Contrôles Techniques, 1947, vol. 1, Oct., pp. 209–211). The technique of microradiographic

tests and their possible uses are briefly discussed.—R. F. F.

Some Experiments Using Two Pendulums in Resonance. C. Sălceanu and M. Borneas. (Comptes Rendus, 1948, vol. 226, Mar. 22, pp. 992–994). Continuing their experiments (*see* Journ. I. and S.I., 1948, vol. 158, Mar., p. 408) the authors report further results using aluminium, silver, brass, copper, iron, nickel, and steel wires.—J. C. R.

Supersonic Flaw Detectors. D. C. Erdman. (Electrical Engineering, 1948, vol. 67, Feb., pp. 181–185). The principles and apparatus used for supersonic flaw detection in metals are explained. Circuit diagrams for a radio-frequency pulse generator, and a portable flaw detector are presented. The limitations of the quartz crystal are pointed out, and applications of the method in the aircraft industry are discussed.—R. A. R.

Detection of Corrosion using Gamma Rays and Supersonic Waves. L. S. McCaslin. (Oil and Gas Journal, 1947, vol. 46, Oct. 18, pp. 100–103, 135, 139, and 141: [Abstract]. Machines et Métaux, 1948, vol. 32, Mar., p. 13). The "Penetron" and the "Audigage," two new instruments for the detection of corrosion are described. The thickness of a wall of a cylinder or container, can be measured by applying the instrument to the external force. The "Penetron," based on the use of gamma rays will measure thickness up to 20 mm. The "Audigage," based on phenomenon of mechanical resonance, is suitable for thicker materials. The use of these instruments in a refinery is discussed.

The Physical Properties of a Pile of Sheets during Heating. P. V. Kobiakov. (Stal, 1948, No. 2, pp. 143–147). [In Russian]. The thermal properties of the anisotropic system formed by a pile of thin metal sheets are discussed, changes in thermal conductivity with the temperature of the pile and the thickness of the air gaps between the sheets and the temperature-distribution in the pile after various times of heating being considered. Experiments are described in which piles of 45–70 sheets (200 × 200 × 0·49 mm.) of light sheet-iron were stacked in a special furnace, the top and bottom sheets of the pile being in contact with electrically heated plates. By means of thermocouples arranged at four points in the pile, the temperature distribution was determined. The figures for thermal conductivity obtained agree fairly well with the theoretical values, and it is seen that the thermal conductivity in the direction perpendicular to the planes of the sheets is only 1–2% of the conductivity of the metal. It is concluded that most heat is absorbed by the sides of the pile, and the rate of heating of the sides is thus not affected by its height; it is pointed out that the production capacity of ovens heating sheets can be increased by allowing for these facts in their design.—S. K.

Raising the Creep Limit by Cold Working. H. Zschokke. (Brown Boveri Review, 1946, vol. 33, Sept., pp. 227–233). The relationship between the DVM (German Society for Testing Materials) creep limit and the amount of previous cold work has been investigated at different temperatures using three 18/8 steels with additions of tungsten, titanium, tantalum plus niobium, and molybdenum, with the following results: (1) Above 750° C. the creep limit is lowered, but above 400° C. raised, for all amounts of cold work; (2) at one definite intermediate test temperature the creep limit attains a maximum with increasing cold work, but then drops off rapidly; (3) the increase in creep resistance obtainable by cold work is greatest at low test temperatures, no further benefit accruing above about 700° C.; and (4) for every amount of cold work there is a definite critical temperature above which the creep limit is impaired instead of enhanced, or alternatively there is an optimum amount of cold work for each service temperature.

Rods reduced in section by 20% during the last pass, but at different rolling temperatures, were tested in the as-rolled condition with the following results: (1) The creep limit rises with decreasing rolling temperature; (2) the increase in creep resistance is greatest at low test temperatures and ceases above about 650° C.; (3) rolling temperatures between 1000° and 660° C. produce no definite maximum creep limit, showing that the critical rolling temperature, if any, lies below 660° C. None of the test-pieces showed any tendency to embrittlement due to precipitation hardening. It is to be anticipated that the enhanced strength will be maintained for long periods up to working temperatures of 600–620° C.—R. A. R.

Intermediate Alloy Steels at Elevated Temperature. R. F. Miller. (Petroleum Engineer, 1948, vol. 19, No. 4, pp. 178–189; Chemical Abstracts, 1948, vol. 42, Mar. 20, col. 1861). Available data are summarized for the physical properties at 370–760° of ten molybdenum steels of high creep strength.

Heat-Resisting Cr–Si–Cu and Cr–Si–Al Steels. M. P. Braun. (Stal, 1948, No. 1, pp. 60–63). [In Russian]. The effects of heat-treatment and of additional alloying elements on the properties and microstructures of chromium steels (Cr 5·03–27·20% and C 0·14–0·53%) were investigated. Both the carbide phase and the chromium solid solution were found to be greatly affected when high- or medium-chromium steels were alloyed with silicon–copper–aluminium or silicon–copper–molybdenum up to a total content of 6%. The high-temperature properties of the chromium steels considered were seen to be improved by alloying with the group silicon–copper–molybdenum, silicon–copper–aluminium, or silicon–aluminium–molybdenum. Most satisfactory properties were noted with two steels having the following compositions: C 0·20%, Cr 20%, Si 2·50%, Cu 2·5%; and C 0·50%, Cr 8·0%, Si 2·50% Al 2·50%, Mo 1·5%. Such steels might well replace chromium–nickel steels for work at temperatures of 1100–1200° C.—S. K.

Contribution to the Study of Gases Dissolved in Steels and Arc Welded Deposits. P. Dewinter. (Ingénieur Chimiste, 1948, vol. 30, Mar., pp. 15–20). The author presents the results of his investigations on the following subjects: The deleterious effect of gases in steels and weld beads; the respective influences of oxygen, nitrogen, and hydrogen on the physicochemical and mechanical properties of steels; and the necessity for properly drying the welding electrode to eliminate dampness and dissolved hydrogen in weld deposits.—J. C. R.

The Passage of Hydrogen Through Iron. Geneviève Sutra and E. Darmois. (Comptes Rendus, 1948, vol. 226, Jan. 12, pp. 177–179). A thin sheet of iron was placed with one face in an acid solution of variable *p*H and the other face in a vacuum. The rate of diffusion of hydrogen and loss in weight of the iron were measured. On the basis of the results quoted, it is considered that the hydrogen diffusing through the iron is atomic in nature. The suggested mechanism is that H^+ ions are adsorbed by the iron; these penetrate into the metal and an atom of iron gives up two electrons to two H^+ ions; the resultant Fe^{++} ion passes into solution and two hydrogen atoms are formed.—M. A. V.

Effects of Alloying Elements on the Microstructure and Properties of Steel. J. M. Hodge. (Steel Processing, 1947, vol. 33, Dec., pp. 746–750). Data are presented relating to a large number of alloying elements to indicate whether they increase hardenability, strengthen ferrite, form carbides, and improve creep strength, and what

other functions they perform. Their effect on transformation behaviour is discussed, and the difference between the transformation of austenite on continuous cooling and at constant temperatures is explained with the aid of a transformation-temperature diagram.—R. A. R.

The Effect of Alloying Elements on the Brittle Strength of High-Durability Steels. Ya. M. Potak and E. L. Booshmanova. (Stal, 1948, No. 1, pp. 64–68). [In Russian]. A number of elements were separately alloyed with a steel containing 0·40–0·44% of carbon and the breaking loads of quenched and annealed specimens were determined. Taking these breaking loads as measures of the brittle strengths of the steels, the following conclusions can be drawn : (1) Alloying with nickel, chromium, copper or tungsten increases the brittle strength, and a similar effect is produced by the presence of even small quantities of the strongly carbide-forming elements vanadium, titanium or molybdenum ; (2) aluminium, manganese or silicon have only a very slight effect, and lead up to 0·18% and sulphur up to 0·10% have no effect on the brittle strength of the steel in which they are alloyed ; (3) in general, the effect of alloying elements on the brittle strength of steel diminishes with increasing temperature of annealing of the tempered specimen.—S. K.

The Influence of Molybdenum on the Properties of Iron Castings. S. S. Nekrytyi. (Stal, 1948, No. 2, pp. 167–172). [In Russian]. Data on the effects of molybdenum on the mechanical properties of castings of various cast irons are presented and discussed. Additions of 0·1–1·0% of molybdenum considerably restrict graphitization both in eutectic and eutectoid crystallization. Molybdenum also greatly increases the dispersion hardening, hardness, resistance to wear (especially in combination with chromium and nickel), and the corrosion and creep resistance ; on the other hand, molybdenum minimizes the decrease in tensile strength and elastic limit which normally occurs at high temperatures. In general, its beneficial effects on the properties of a casting increase with decreasing carbon content. The chemical composition, tensile strength and Brinell hardness of a number of molybdenum-bearing grey cast irons are tabulated together with their applications. The various ways of adding the molybdenum are briefly discussed, the use of ferro-molybdenum, calcium molybdate, molybdenum-bearing briquettes, and cast irons or scrap for this purpose being considered. It is concluded that the determination of molybdenum in scrap for use in the cupola would result in closer control of the properties of casting.—S. K.

Steel Foundry Substitute Steels. G. Delbart. (Association Technique de Fonderie, 1941). An account is presented of tests carried out on chromium–molybdenum and chromium–manganese steels of varying compositions. The properties of these steels and their use as a substitute for chromium–nickel steels are discussed.—J. C. R.

Boron-Treated Steels. (National Bureau of Standards Technical Report No. 1175 : British Steelmaker, 1948, vol. 14, Mar., pp. 144–146 ; Blast Furnace and Steel Plant, 1948, vol. 36, Mar., pp. 345–346, 362 ; Steel Processing, 1948, vol. 34, Mar., pp. 144–146). The results of an investigation by the National Bureau of Standards on the influence of boron on the hardenability of steel are reported. Variations from nil to 0·006% of boron additions made with either simple or complex intensifiers had no significant influence on the following properties : (1) Cleanliness (except for titanium or zirconium inclusions in some steels treated with complex intensifiers) ; (2) hot working ; (3) transformation temperatures ; (4) resistance to softening by tempering ; (5) weldability ; and (6) tensile properties of fully hardened and tempered specimens. Boron lowers the coarsening temperature of austenite. The increase in hardenability due to boron is greater for basic open-hearth steels than for experimental steels prepared in an induction furnace.—R. A. R.

Sulphur Steels. (Technique Moderne, 1947, May 1–15, pp. 163–165 : [Abstract]. Chaleur et Industrie, 1948, vol. 29, Mar., p. 15D). The addition of sulphur makes steel hot and cold short. This is due to the presence of iron sulphide in the crystal boundaries, but with an increased manganese content (more than 0·6%) a manganese sulphide is formed which reduces hot brittleness and facilitates rolling. Steels containing 0·1–0·2% of sulphur and 0·6–1% of manganese are more easily machinable than sulphur-free steels and greater cutting speeds can be obtained. An account of the manufacture of these high-speed free-cutting steels at the Pompey works in France is given.

Influence of Niobium on the Properties of High Speed Steel Having a Low Tungsten Content. N. T. Goudtzov and L. D. Machtakowa. (Izvestia Akademia Nauk, U.S.S.R., 1947, No. 12, pp. 1629–1637 : [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Mar., p. 1). The addition of niobium lessens the cutting properties of high-speed steel. The fact that niobium and tungsten are both present reduces considerably the plastic qualities of steel and its forgeability. A reduction in the temperature range during hardening is noticed.

Determination of the Viscosity of Molten Alloys and Its Applications. S. V. Sergeev and E. V. Polyak. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 336–344 : Chemical Abstracts, 1948, vol. 42, Mar. 10, col. 1545).

Sands and Cast Iron. F. Girardet. (Association Technique de Fonderie, 17 Dec., 1943). This is an abridged account of a paper in which the author first describes the use of a Charpy micropendulum appliance, suitably adapted, to measure the impact strength of moulds and cores. He then considers the pearlite and austenite transformation points in cast iron and describes a "tropometer" which indicates quickly, accurately, and cheaply when the austenitic transformation point has been reached. It is based on the fact that cast iron ceases to be magnetic at the austenite point, and does not regain this attribute until the pearlite transformation point has been passed. The essential part of the tropometer is a minute electric furnace (8 mm. in dia.) which can be heated and cooled quickly many times without causing any change in the chemical composition of the metal. Repeated transitions through the pearlite and austenite points have not caused thermal fatigue but have improved the texture and mechanical strength of the iron. The varying effects on the austenitic and pearlitic transformation points and hysteresis of operating the tropometer in air, in a vacuum, and in hydrogen are compared.—J. C. R.

Steel for a Stamping Instrument. G. L. Livshits. (Stal, 1948, No. 2, pp. 153–156). [In Russian]. The properties of a series of low-tungsten steels were investigated and the results described. The use of these steels for pressings is discussed.—S. K.

Sulphuric Resistant Stainless Now Produced in Wrought Forms. (Steel, 1948, vol. 122, Jan., pp. 90–92). **Sulfuric Acid-Resistant Stainless Steel Now Available in Wrought Form.** (Materials and Methods, 1948, vol. 27, Feb., pp. 80–82). A new material called "Carpenter Stainless No. 20" which is a wrought form of stainless steel with a very high resistance to sulphuric acid is now available. The composition is approximately chromium 20%, nickel 29%, molybdenum 2% min., copper 3% min.,

and carbon 0·07% max. Data on its mechanical and physical properties are given.—R. A. R.

Tool Steels. (Machinery Lloyd, 1947, Nov., No. 25A, pp. 58–68 : [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Feb., p. 1). An account is given of the properties, composition, working, and heat-treatment of various tool steels.

Modern High-Speed Tool Steels. O. Zmeskal. (Journal of the Western Society of Engineers, 1947, vol. 52, Dec., pp. 155–161). After dealing with the early history of high-speed steels, the author describes the success of the attempts in recent years to replace part, or all, of the tungsten in this type of steel by molybdenum. Of other alloying elements, vanadium which increases both "hot-hardness" and resistance to abrasion, cobalt which increases shock-resistance, and boron which reduces the hardening temperature, are the most valuable. In most types of tool, the author considers heat-treatment is more important than analysis and gives simple rules for this which ensure that all the high-temperature structure is transformed ; he states that new, so-called "revolutionary" processes of heat-treatment have no advantages over standard methods.

Hard chromium plating and nitriding by quenching in a cyanide bath improve the cutting performances of high-speed steel tools considerably, but the greatest advantages are to be expected from the efficient use of sintered-carbide-tipped tools ; this will call for the redesign of machine-tools.—J. P. S.

Bearing Steels Meet High Quality Standards. E. M. Taussig and C. B. Cobun. (Steel, 1948, vol. 122, Feb. 23, pp. 100–103). The care taken in the production of steel for bearings is discussed and some specifications of bearing steels are given.—R. A. R.

Cast Iron Offers Combination of Properties Not Found in Other Materials. N. G. Meagley. (Materials and Methods, 1948, vol. 27, Feb., pp. 83–86). The properties of cast iron are discussed and it is stressed that the modern methods of manufacture and heat-treatment make possible a wide range of properties which extend the usefulness of the material.—R. A. R.

Limitations on Precision Cast Parts. N. J. Great. (Iron Age, 1947, vol. 160, Aug. 7, pp. 62–66). As a result of investigations on turbine blades made by the precision-investment-casting process it is suggested that the limitations of the process make it difficult entirely to evaluate their performances on the basis of rupture and creep tests. Radiographic studies and density determinations on a high carbon Vitallium alloy (C 1·1%, Cu 24·0%, Co 65%, Mo 6%, Ta 2%) indicate that for long blade sections, sufficient taper must be provided to allow directional solidification.—J. P. S.

A New Cast Iron: The Nodular Graphite Structure. J. G. Pearce. (Society of Chemical Industry, Apr. 6, 1948, Advance Copy). An outline is given of the production of a cast-iron containing nodular graphite in the as-cast state by the addition of a small and controlled amount of cerium to the molten metal. The mechanical properties, analyses, and effects, of subsequent heat-treatment on a number of these irons are presented.—R. A. R.

The Specification and Testing of Cast Iron. A. B. Everest. (Institute of British Foundrymen : Foundry Trade Journal, 1948, vol. 84, Apr. 1, pp. 317–321). An account is given of the work undertaken by the committee appointed by the Technical Council of the Institute of British Foundrymen in conjunction with the British Standards Institution in the drafting of specifications for cast iron.—R. A. R.

The New Specifications B.S. 309 and 310 (1947) for Malleable Cast Iron. S. W. Palmer. (Bulletin of the British Cast Iron Research Association, 1948, vol. 9, Mar., pp. 137–139). The new British Standard Specifications for whiteheart and blackheart malleable cast iron are discussed.—R. A. R.

Surface Finish Measurement Instrumentation. J. A. Broadston. (Instruments, 1947, vol. 20, Apr., pp. 374–376 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 32). The industrial necessity of identifying the degree of surface finish by a number is discussed.

Electronics in Industry. D. Michell and G. W. West. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy, Part 4, Physical Apparatus for Metallurgical Measurements, 1947, Sept.). A résumé is presented of the basic principles of electronics with descriptions of many examples of the application of electron tubes and electronic circuits in the various fields of metallurgy.—R. A. R.

The International Exhibition of Scientific Research and Industrial Control. (Revue Universelle des Mines, 1948, Series 9, vol. 4, Jan.). This issue of Revue Universelle des Mines is devoted to the centenary celebrations of l'Association des Ingénieurs sortis de l'École de Liège, and to the exhibition held in connection with them. Abstracts of papers of ferrous interest follow.

Metallurgical Laboratory. H. Herliet. (*Ibid.*, pp. 20–25). Descriptions are given of the testing equipment and instruments at a stand representing a metallurgical laboratory.

Foundry Laboratory. J. Léonard. (*Ibid.*, pp. 30–32). The exhibit of foundry laboratory equipment is described.

Ore-Treatment Laboratory at the University of Liège. E. Frenay and J. Deladrière. (*Ibid.*, pp. 43–46). The rebuilt laboratory for ore-treatment at the University of Liége is described.

Laboratory for the Study of Structures and of Photo-Elasticity. A. de Marneffe. (*Ibid.*, pp. 64–66).

Lubrication Studies. C. Hanocq and L. Leloup. (*Ibid.*, pp. 82–86). The exhibit of equipment for lubrication investigations is described.

Stamping. L. Leloup. (*Ibid.*, pp. 86–87). The stand exhibiting stamping machinery is described.

METALLOGRAPHY

Recent Advances in Electron Microscopy in the United Kingdom. V. E. Cosslett. (Electron Microscope Society of America : Research, 1948, vol. 1, Apr., pp. 293–304). Some results of recent investigations using advanced electron-microscope techniques are described. The examples cited include the particle size and shape of smokes and dusts, and metallurgical and biological work. F. W. Cuckow's work on a comparison of techniques for obtaining replicas of solid surfaces is quoted. The conclusion was that, even though the silica replicas lead to the sharpest micrographs, they inspire less confidence than the plastic film replicas. Furthermore, electron micrographs of the latter show a marked gain over photomicrographs, not only in their greater definition, but also in their ability to determine the geometry of the surface.—R. A. R.

Electron Microscopy. X-Ray Diffraction and Spectrochemistry. P. Coheur. (Revue Universelle des Mines, 1948, Series 9, vol. 4, Jan., pp. 25–30). The principles of electronic microscopy. X-ray diffraction and spectrochemistry are briefly surveyed.—R. F. F.

Applications of the Electron Microscope in Metallography. J. Hunger and F. Pawlek. (Archiv für Metallkunde, 1947, vol. 1, Sept., pp. 385–400). Replica

techniques for use with the electron microscope are reviewed, with examples of the application of the oxide double-replica process to iron and steel and some non-ferrous alloys.

The technique is used for studying transformation and precipitation-hardening in these alloys and it is pointed out that while the hardening due to phase-transformations in cooling is rapid and considerable, precipitation from a supersaturated solution at room temperature occurs first as minute particles not visible with the optical microscope, before the coarser and more stable particles appear.—J. P. S.

A New Experimental Electron Microscope. G. Liebmann. (Journal of Scientific Instruments, 1948, vol. 25, Feb. pp. 37–43). An experimental universal electron microscope of high magnification is described which deviates in many ways from the known types. The instrument, intended as a self-contained desk model, employs four permanently aligned magnetic lenses and optical magnification. A new type of specimen stage, permitting a quick exchange of specimen, wide-angle stereoscopic observations and direct calibration of specimen position and an improved electron gun are used. The camera head is exchangeable. The instrument can be quickly adapted for electron diffraction observations. Possibilities of further development are discussed.

Electron Microscopy in Germany. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1671: H.M. Stationery Office). This report directs the research worker to the right sources of information on German electron microscopes and the investigations which have been made with them. It consists for the most part of a bibliography for the period 1939–45 and a subject index.—R. A. R.

Examination of Ingots, Billets and Heavy Wall Tubes for the Production of Roller and Ball Races. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 619 (Addendum No. 1) : H.M. Stationery Office).

The Casting Skin, Its Formation, Properties, and Relation to Other Properties of Cast Iron. F. Diepschlag. (Technik, 1948, vol. 3, Jan., pp. 15–21). The nature, composition, formation, and effects of the skin or surface layer on iron castings are discussed. Tables are presented showing the difference in composition between the surface and core of sand-cast and chill-cast iron, and several micrographs of the surface structure are shown. Finally, the resistance to corrosion afforded by the skin is pointed out. Attempts have been made to produce a skin consisting of evenly distributed iron oxide and iron silicate which would give excellent adhesion to a subsequent enamel coating.—R. A. R.

Ferrous Alloys—Investigation of Electrolytic Etching Solutions. W. I. Pumphrey. (Iron and Steel, 1948, vol. 21, Mar., pp. 75–80). This paper records an extension of H. J. Merchant's investigation of electrolytic polishing (*see* Journ. I. and S.I., 1947, vol. 155, Feb., p. 179) to those ranges of potential and electrolyte composition in which electrolytic etching, but not polishing, of a steel specimen occurs. A 20% aqueous solution of chromic acid was found suitable for the electrolytic etching of most ferrous alloys. The nature of electrolytic etching is briefly discussed and it is suggested that the etching effect depends on : (1) The nature of the electrolyte, whether acid or basic ; (2) its degree of ionization ; (3) the solubility of the oxides of iron, or of other components, in the electolyte ; and (4) the current density at the anode.—R. A. R.

Fractography—The Study of Fractures at High Magnification. C. A. Zapffe, F. K. Landgraf, jun., and C. O. Worden, jun. (Iron Age, 1948, vol. 161, Apr. 1, pp. 76–82). "Fractography" or the study of cleavage facets at high magnification, has already been described (*see* Journ. I. and S.I., 1945, No. I, p. 63). In this paper 13 "fractographs" are reproduced and their principal features are discussed. They include non-ferrous metals and silicon–iron and chromium–iron alloys. A study of the fractographs reveals information unattainable by conventional polishing and etching methods.—R. A. R.

Kinetics of Grain Growth of Austenite in Boron Steels. S. M. Vindrov. (Comptes Rendus de l'Académie des Sciences, U.R.S.S., 1947, No. 9, pp. 809–811 : [Abstract]. Centre de Documentation Sidérurgique, Bulletin Analytique, 1948, vol. 5, Jan., p. 23). Grain-growth curves were plotted as a function of the boron content of the steel and the period of heating at 900° C. The critical surface theory enables an explanation to be devised which is confirmed by experience.

Methods for Crystallographical Determinations—The Barker Method. W. G. Perdok. (Chemisch Weekblad, 1948, vol. 44, Apr. 10, pp. 202–207). [In Dutch].

Study of the Recrystallization of a Special Austenitic Chromium–Nickel Steel. A. Portevin and R. Castro. (Bulletin de l'Association Technique de Fonderie, 1940, Mar.–Apr., pp. 47–50). Specimens of an austenitic chromium–nickel steel (C 0·045%, Si 0·14%, Mn 2·26%, Ni 25·1%, Cr 12·18%) were bent and reheated to 1000° C. Tests showed sharp variations in recrystallization. From the results obtained the authors have prepared diagrams showing variations in grain growth and hardness in their relation to cold work and annealing temperature. The influence of overheating when specimens were heated to 1200° C. is briefly considered.—J. C. R.

Maintenance of Haulage Cables: Metallographic Examination. G. Jacques. (Prévention des Accidents et Contrôles Techniques, 1948, vol. 2, Apr., pp. 135–139). The comparison of micrographs of mine cables when new, and after use, shows changes occurring in the strands during service.—R. F. F.

The Carbides in Iron–Carbon–Silicon Alloys and Cast Irons. D. Marles. (Journal of The Iron and Steel Institute, 1948, vol. 158, Apr., pp. 433–436).

Grand Prize: 1947 A.S.M. Metallographic Exhibit. R. H. Hays. (Metal Progress, 1948, vol. 53, Mar., pp. 374–375). Two large micrographs of the same area of a specimen of 5%-chromium 1%-molybdenum steel, at 200 diameters, are reproduced ; one shows the structure as-quenched from 2250° F., and the second, after cooling to −110° F.—R. A. R.

The Graphitization of Steels. M. Pelabon and J. Ivernel. (Bulletin du Cercle d'Études des Métaux, 1948, vol. 5, Mar., pp. 29–55). The authors give an account of tests to study the influence of hardness on the speed of graphitization, by reheating a hypereutectoid steel (C 1·2%, Si 0·77%, S 0·025%, P 0·09%, Mn 0·9%, Al 0·1%) and a eutectoid steel (C 0·84%, Si 0·23%, S 0·012%, P 0·026%, Mn 0·58%) below their Ac_1 points. Three groups of tests on the hypereutectoid steel were carried out ; in the first the steel in the as-forged condition was heated above the Ac_3 point ; in the second the steel as-forged was heated below the Ac_1 point; and in the third the steel, previously quenched in oil, was heated below the Ac_1 point. The results are presented and the effect on graphitization of the following factors is discussed : Preliminary heat-treatment, graphitization temperature, cooling and heating speeds. Only one series of tests was carried out on the eutectoid steel at 625° C. after annealing at 800° C. and quenching in oil at 1100° C. A review is also given of the work of various investigators on the graphitization of hypo-eutectoid steels.—J. C. R.

The Production of Nodular Graphite Structures in Cast Iron. H. Morrogh and W. J. Williams. (Journal of The Iron and Steel Institute, 1948, vol. 158, Mar., pp. 306–322).

Nonmetallic Grain Boundary Material in Carburized Cases. J. J. Kary. (Metal Progress, 1948, vol. 53, Feb., pp. 218–222). Carburized machine parts are often covered with a light scale on removal from the case-hardening medium ; this scale outlines the grain boundaries at the surface. An investigation of the effect of different media and different case-hardening temperatures on the scale and its penetration into the grain boundaries is reported. A 5% nickel steel and other alloy steels were used for the tests.—R. A. R.

A Rapid X-Ray Method for the Determination of the Orientation of Single Crystals or Large-Grained Polycrystalline Aggregates. A. E. De Barr. (Journal of Scientific Instruments, 1948, vol. 25, Mar., pp. 102–104). A type of goniometer is described which enables a crystal to be set in a given orientation. The method makes use of strong high-Bragg-angle reflections which can be received on a fluorescent screen. The orientation of any given face of the crystal can readily be calculated from the readings of two angle scales on the instrument, and can be plotted on a stereographic projection. The calculations necessary for plotting the crystal face are given in an appendix.

Equipment for X-Ray Crystallography. T. L. Tippell. (Instrument Practice, 1948, vol. 2, Mar., pp. 189–190, 196). Some disadvantages of the completely sealed type of X-ray tube are pointed out and a brief description is given of the Hilger " H.R.X. " diffraction unit which employs a continuously evacuated hot-cathode, demountable X-ray tube with four separate windows and pivoted filter holders.—R. A. R.

Elastic Anistrophy of a Thin Sheet of Cold Rolled Invar. P. J. Bouchet. (Comptes Rendus, 1948, vol. 226, Apr. 12, pp. 1168–1169). A sheet of invar (35·5% nickel) was hot rolled to a thickness of 3·5 mm. and then cold rolled down to 0·7 mm. X-ray diffraction analysis showed a superposition of two orientations ; plan (110) and direction [112], and plan (112) and direction [111], both parallel to the direction of rolling. Young's modulus, measured on a Chevenard instrument, was 13,500 kg./sq. mm. which decreased as the angle α (between the axis of the test-piece and the direction of rolling) increased, reaching 7800 kg./sq. mm. when $\alpha=45°$, and then increasing and reaching 12,000 kg./sq. mm. when $\alpha = 90°$. Results obtained after annealing at 1100° for 2 hr. in a vacuum indicate a complete recrystallization to a cubic structure, of plan (100) and direction [100] both parallel to the direction of rolling. Young's modulus, in this state, is 5100 kg./sq. mm. both parallel and at right angles to the direction of rolling and reaches a maximum, 10,200 kg./sq. mm. in the [110] direction $\alpha=45°$. It is claimed that Young's modulus measurements provide a simple means of indicating the progress of recrystallization.—J. C. R.

X-Ray Identification of Sigma Phase in 25-20 Cr–Ni Stainless. W. J. Barnett and A. R. Troiano. (Metal Progress, 1948, vol. 53, Mar., pp. 366–367). An X-ray technique is described by which small amounts of the sigma phase in fine-grained low-silicon 25/20 chromium-nickel steel can be identified. The method used is to etch a strip of the metal electrolytically in aqueous ferric chloride ; the austenitic matrix is selectively etched, resulting in an effective increase in concentration of the sigma phase, which is then readily identifiable by its X-ray diffraction pattern.—R. A. R.

The Formation of Sigma Phase in Duplex Chromium–Nickel–Molybdenum Corrosion-Resisting Steels. H. W. Kirkby and J. I. Morley. (Journal of The Iron and Steel Institute, 1948, vol. 158, Mar., pp. 289–294).

The Occurrence and Some Effects of Sigma Phase in a Molybdenum-Bearing Chromium–Nickel Austenitic Steel. L. Smith and K. W. J. Bowen. (Journal of The Iron and Steel Institute, 1948, vol. 158, Mar., pp. 295–305).

Comparison of Metallographic and X-Ray Measurements of Retained Austenite. W. J. Harris, jun. (Nature, 1948, vol. 161, Feb. 28, pp. 315–316). The amounts of retained austenite in a 1·1% carbon, 1·4% chromium steel after quenching in oil from 788°, 843°, 899°, and 954° C. were determined by etching and by X-ray measurements and good agreement was obtained. The nital etch was improved by adding a wetting agent called " Zephiran Chloride."—R. A. R.

Intermediate Phases in Metallic Alloys. L. Jeníček. (Hutnické Listy, 1948, vol. 3, No. 2, pp. 37–41). [In Czech]. The electronic theory of the metallic state developed by Kurnakov and Glazunov and the nature of daltonides and berthollides, are discussed—R. A. R.

Elastic Relaxation and Some Other Properties of the Solid Solutions of Carbon and Nitrogen in Iron. L. J. Dijkstra. (Philips Research Reports, 1947, vol. 2, Oct., pp. 357–381). The theory of elastic relaxation in α-iron caused by carbon and nitrogen in solid solution, as given for the first time by Snoek and later elaborated by Polder, predicts a strong anisotropy for the various crystal directions. This theoretical conclusion has been confirmed in a series of experiments carried out on prepared single crystals of iron in the [100]- and [111]-directions. The author checked the theoretical absolute magnitude of the effect for carbon. The question of the most probable place of the dissolved particles in the iron lattice is also discussed. Finally at 20° C. the rate of segregation taking place in the form of a carbide or nitride has been determined by measuring the decrease in magnitude of the elastic relaxation in the course of time.—R. A. R.

Self-Diffusion in Iron. C. E. Birchenall and R. F. Mehl. (Journal of Applied Physics, 1948, vol. 19, Feb., pp. 217–218). The rates of self-diffusion in α- and γ-iron have been determined by radio-active tracer techniques in the 715°–887° and 935°–1112° C. ranges respectively. When both curves were extrapolated to the transformation temperature 910° C. it is found that the rate in α-iron is about 100 times that in γ-iron. Great differences in the activation energies in the two phases with correspondingly larger differences in the frequency factors were observed. The frequency factors obtained experimentally and from the Dushman-Langmuir equation are compared.—R. A. R.

The Mechanism of the γ–α Transformation in Iron. H. Neerfeld. (Kaiser-Wilhelm-Institut für Eisenforschung : Stahl und Eisen, 1948, vol. 68, Mar. 25, p. 128). A brief summary of the results of investigations by the author and K. Mathieu on the γ–α transformation is given. In tensile tests on austenitic steel wires in the course of which the deformation caused transformation there was a change in the known α-iron orientation from [110] to [210] ; X-ray determinations showed that in the new orientation the total distance traversed by the atoms was at a minimum and that the displacement of the atoms was almost entirely in the direction of the applied stress.—R. A. R.

The Decomposition and Products of the Transformation of Austenite at Sub-Critical Temperatures. F. A. Hamilton. (Australian Institute of Metals : Australasian Engineer, 1947, Dec. 8, pp. 52–61). This is a review of recent literature on the modern theories of the mechanism of formation and changes of microstructure when a steel is

heated and cooled. There are 42 references.—R. A. R.

The Determination of Equilibrium Diagrams. G. V. Raynor. (Journal of the Birmingham Metallurgical Society, 1948, vol. 28, Mar., pp. 3–36). After explaining the practical and theoretical importance of accurate equilibrium diagrams for alloys, the author describes: (*a*) Methods of obtaining liquidus curves by thermal analysis; (*b*) the construction of solidus curves; (*c*) the micrographic method for examining solid solubility curves; and (*d*) X-ray methods of obtaining data for equilibrium diagrams.—R. A. R.

Phase Diagrams. L. Grenet. (Echo des Mines, 1947, Oct., pp. 164–165; Nov., pp. 188–189; Dec., pp. 210–211). Phase diagrams, the theories underlying them, and their purposes, are briefly reviewed.—R. F. F.

CORROSION

Use of Inhibition in Corrosion Control. N. Hackerman. (Corrosion, 1948, vol. 4, Feb., pp. 45–60). Recent published literature on corrosion inhibitors is reviewed. A bibliography of 59 references to the literature is appended.

Soluble Silicates for Corrosion Inhibition in the Oil Industry. W. Stericker. (Corrosion, 1948, vol. 4, Feb., pp. 83–92). The compositions of some proprietary sodium-silicate type corrosion inhibitors are listed, and examples given of their efficacy in the treatment of both brine and fresh water in oil refineries.—M. A. V.

Corrosion Tests in Sulfuric Acid in Petroleum Refinery Processes. W. Z. Friend. (Corrosion, 1948, vol. 4, Mar., pp. 101–111). Tests were carried out to determine the corrosion resistance of various metals and alloys to sulphuric acid attack under refinery conditions; the iron alloys tested included 19/9, 18/13/3 chromium–nickel–molybdenum, and 25/20 stainless steels, mild steel, Ni-Resist, high-silicon and ordinary cast irons, and some nickel–chromium–molybdenum–iron alloys such as Durimet and Worthite. Of these, Durimet-type alloys could be used for pumps handling acid sludge; silicon cast irons for pumps handling 45–65% H_2SO_4 at up to 240° F.; mild steel for concentrated acid at low temperatures on alkylation plant, or stainless steel if turbulent conditions were encountered; and silicon cast irons in separator tanks when the air was diluted with steam and in reconcentration tanks. For most purposes in the refining, nickel-base alloys are preferable.—M. A. V.

Passivity of Chromium. N. Hackerman and D. I. Marshall. (Journal of the Electrochemical Society, 1948, vol. 93, Mar., pp. 49–54). Surfaces of chromium, treated in nitric acid and oxidized in air at various temperatures, up to 600° C., were examined by electron diffraction, while electrode potential measurements in a saturated potassium chloride electrolyte with a calomel half-cell were made on similar specimens. Results indicate that oxide films appreciably alter the values of the electrode potentials of the metal surface, that the metal can exhibit a noble potential even when no oxide film can be detected by electron diffraction, that the noble potentials obtained with oxide films need not be identified with passivity, but may be due to a property of the oxide itself, and that the potential of chromium treated with nitric acid is more noble than that of the air-treated metal, and most noble when the metal is not subsequently air-treated.—J. P. S.

Magnesium Anodes for Protective Water Heaters and Storage Tanks. (Modern Metals, 1948, vol. 4, Mar., pp. 32–33). Magnesium anodes will protect galvanized hot water tanks from corrosion to a considerabe extent, and to a lesser extent if copper parts are also coupled to the tank.—J. P. S.

Method for the Study of Surface Reactions. E. Jandon. (Métaux, Corrosion, Usure, 1944, vol. 19, Jan., pp. 12–17). An electrical method for the study of electrolytic corrosion is described, and particulars are given of its application to the study of untreated, and of phosphated, metal surfaces. The test electrode is combined with a calomel electrode in the corroding solution to form a cell; a condenser may be alternatively charged by the cell, and discharged though a resistance and a ballistic galvanometer in series, which shows the e.m.f. to be measured at any moment. The function $(E_0-E)/(E-E_F)$, where E_0, E, and E_F are respectively the e.m.f.s initially, at a given time, and finally (after corrosion is well advanced), is plotted against the time. The interpretation of the curves so obtained serves as a quicker alternative to weight-loss measurements.—M. A. V.

Corrosion-Preventing Films. F. Ritter. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Jan.–Mar., pp. 42–44). The mechanism of the prevention of corrosion and scale formation by protective films is reviewed. R. A. R.

New Theory for Corrosion of Carbon Steel. W. C. Hull. (Petroleum Processing, 1947, vol. 2, June, pp. 405–408: [Abstract]. Corrosion, 1948, vol. 4, Apr., p. 12). This is a critical discussion of a new theory that the structure of the carbide crystals in steels is the important factor controlling corrosion. Metal surface areas rich in lamellar pearlite are said to be more resistant than areas in which the carbide structure is in the spheroidized form.

Rate of Oxidation of an Austenitic Iron–Chromium–Nickel Alloy. I. I. Kornilov and A. I. Spikelman. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1946, vol. 54, No. 6, Nov. 30, pp. 511–514: [Abstract]. Corrosion, 1948, vol. 4, Apr., p. 10). Scaling tests of 750 hours' duration were carried out at 1100° and 1200° C. on a steel with 28% of chromium and 27% of nickel. Analysis of the descaled specimens showed that carbon, silicon, and, at 1100° C., carbon, and chromium were preferentially oxidized, while the relative nickel content increased.

Accidents Occurring with Cylinders of Compressed Town Gas (1938–1943). Contribution to the Study of Corrosion Cracking under Pressure. H. de Leiris, J. Couture, and C. Crussard. (Métaux, Corrosion, Usure, 1944, vol. 19, Nov.–Dec., pp. 95–106). An account is given of the stress corrosion cracking of cylinders, in which particular attention is paid to the formation and nature of the cracks. Many accidents had occurred with alloy steel containers and corrosion of alloy steels by hydrocyanic acid was much more rapid than with ordinary steels. Hardened steels were more liable to cracking than annealed steels, and the cracks were deeper. The effects of internal stresses in the metal, the nature of the cylinder's contents and the temperature are considered, and the mechanism of stress corrosion cracking is discussed.—J. C. R.

Control of External Corrosion on Plantation Pipe Line. A. C. Nelson. (Corrosion, 1948, vol. 4, Mar., pp. 123–132). A pipeline running from Louisiana to North Carolina was economically protected by applying coatings to sections in low-resistance soil, using magnesium anodes for cathodic protection, and installing oil-immersed copper-oxide rectifier plates in half-wave stacks to form stray-current drainage units at a number of electric railway crossings. Details of the installation and costs are given.—M. A. V.

Intercrystalline and Other Types of Corrosion of Steam Boilers. R. E. Coughlan and others. (American Railway Engineering Association, 1947, Nov., Bulletin 469:

pp. 66–67 : Chemical Abstract, 1948, vol. 42, Apr., 2373). Railroads are testing all-welded boilers to prevent damage from intercrystalline cracking caused by adverse water conditions.

The Mechanism of Protective Action of Alloying Elements in the Sulphide Corrosion of Iron. P. V. Geld and O. A. Essin. (Journal of Applied Chemistry, U.S.S.R., 1946, vol. 19, No. 9, pp. 861–868 : British Chemical Digest, 1948, vol. 2, Apr., pp. 225–227). This is an abridged translation from the Russian. The mechanism of sulphide corrosion of metals used as alloys with iron is discussed and a new theory for the protective action of alloys against sulphide corrosion proposed. This theory explains the protective action of chromium and aluminium and the absence of such action for nickel and manganese.—R. F. F.

Comparative Tests on White-Lead and Zinc-Oxide Paints. A. V. Blom. (Verfkroniek, 1947, vol. 20, pp. 143–145 : British Abstracts, 1948, Section BII, Feb., p. 86). Three typical white-lead paints and three typical zinc-oxide paints on iron and wood panels have been subjected to natural exposure, 45° south, at Zürich (493 m.) and Claradel (1700 m.) A red-lead primer was used for the lead but not for the zinc-oxide paints on the iron. After three years the lead paints were in all cases superior. On accelerated weathering the difference was even more marked, the iron panels coated with zinc-oxide paints rusted through in three weeks, whereas those coated with lead paint were still good after four months.

ANALYSIS

Determination of Vanadium in Manganese Ore. A. Kundert. (Chemist Analyst, 1948, vol. 37, Mar., pp. 16–17). Details are given of a method for determining vanadium in manganese ore, in which the ore is broken down by hydrochloric acid. Separation of the vanadium is made by complete precipitation by zinc oxide in the presence of sufficient iron to occlude the vanadium. When the amount of iron in the filtrate is made up to twice that of the vanadium no boiling is required.

R. A. R.

Reserves and Future of Coking Coals in the United States. F. M. Becker. (American Institute of Mining and Metallurgical Engineers : Blast Furnace, Coke Oven, and Raw Materials Conference, Proceedings, 1947, vol. 6, pp. 3–23). The resources and distribution of different classes of coal in the United States are studied, and their washability characteristics and the effects of ash and sulphur in the coal on the quality of the coke, tar, and coke-oven gas are dealt with from the points of view of both present and future requirements.—R. A. R.

Use of the Spectroscope in the Determination of the Constituents of Boiler Scale and Related Compounds. A. Gabriel, H. W. Jaffe, and M. J. Peterson. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 1111–1120). The simple bunsen spectroscope can be used to determine the metallic elements in boiler scales since over half the elements yield spectra in the visible range when subjected to arc excitation. The setting up of the instrument and its operation are described and some results obtained with boiler scales are discussed.—R. A. R.

Measurement of Water in Gases by Electrical Conduction in a Film of Hygroscopic Material. E. R. Weaver and R. Riley. (Analytical Chemistry, 1948, vol. 20, Mar., pp. 216–229). An apparatus is described which, depending upon the changes in electrical conductivity of a thin film of a conducting compound, such as phosphoric acid, spread upon an insulating material, can be used for determining water vapour in compressed oxygen, liquid CO_2, and Freon, moisture in powdered solids, the permeability of membranes to water, and so on.

A variety of conducting "heads" or detectors can be employed, and the electrical measuring gear is adjustable for a wide range of resistances.—J. P. S.

Rapid Method of Moisture Determination in Coals by High Frequency Currents. I. L. Liplavk. (Zavodskaya Laboratoriya, 1946, No. 6, pp. 555–558 : [Abstract]. Engineers' Digest (London), 1948, vol. 9, May, p. 170).

The Cenco-Derge Rapid Oxygen Determination. J. H. Richards. (American Institute of Mining and Metallurgical Engineers, Open-hearth Proceedings, 1947, vol. 30, (pp. 160–168). A description is given of the Cenco-Derge vacuum-fusion equipment with which the oxygen in a chill-cast sample of steel can be determined in 10 to 20 min. Experience proved that this determination was of practical value in ascertaining the degree of deoxidation of a heat of steel.—R. A. R.

Recent Improvements of a Recording Microphotometer. E. Vassy. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 23–25 June, 1947, 8th Congress, pp. 27–28). In a split-beam microphotometer, in which one beam scans the plate and the other traverses a movable wedge, the out-of-balance current is amplified so as to move the wedge towards a balanced position and operate a recorder. This has been improved by a rotating seven-bladed cylindrical shutter around the lamp and a phase-shifting amplifier circuit ; this allows higher densities to be measured. To compensate for the inertia of the recording pen in recording large densities, a relay has been provided to cut down the traverse speed while the recording pen is moving, and automatically restore the maximum traverse speed when the pen is at rest.—E. van S.

A Detailed Consideration of Methods of Chemical Analysis Based on the Absorption of Light.—Citerne. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 23–25 June, 1947, 8th Congress, pp. 85–102). This is a thorough theoretical examination of the sources of error in photoelectric absorptiometers with practical examples. The effect of dissolved colourless salts on the effective density of a coloured solution due to changes of refractive index is pointed out ; also the effect of temperature changes on the estimation of manganese as permanganate which depends on the colour filter used. For certain solutions, optimum precision may be improved by choosing a colour filter to select a flat portion of the absorption curve even if it is not a maximum.

In the design of absorptiometers considerable accuracy is gained by using the substitution method instead of a direct method or of compensating the output current electrically. Optical densities are best measured in the range 0·2 to 0·8 where the relative error is least.

E. van S.

The Estimation of Small Concentrations of Copper in Steel. J. M. Phéline and R. Castro. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 23–25 June, 1947, 8th Congress, pp. 47–61). Two spectrographic methods and one absorpiometric method are described ; the third one depends on a preliminary precipitation of the copper with sodium thiosulphate, which is dissolved in acid, buffered to a *p*H value of 3·8, and converted into its green complex with rubeanic acid (dithio-oxamide). Calibration lines are given for three types of absorptiometer ; the results agree with synthetic solutions and with the spectrographic measurements on mild steel, chromium steel, and 18/8 stainless steels containing up to 1% of molybdenum, titanium, and copper.

One spectrographic method for solutions was used for alloys in the range 0·1–1% in the absence of reliable standard steels. Solutions of the metal as nitrate were dried on specially purified graphite rods and sparked with a Feussner generator with low self-inductance and high capacity. Results were of moderate precision, because of variations in the porosity of the graphite. The second method is applicable to routine testing of metallic samples. A flat surface is sparked with a pure aluminium counter-electrode, using a Feussner generator and a 3-step wedge in front of the spectrograph slit. Copper is determined in the range 0·02–0·5% and index points are quoted for the comparison of one copper line with a long series of iron lines. For wrought material a spark between two strips of the steel is used ; and the standard deviation of a series of results on the sample is about 6%, as compared with 4·5% for more massive samples. E. van S.

Detection and Colorimetric Determination of Niobium and Tantalum. M. S. Platonov and N. F. Krivoshlikov. (Transactions of the All-Union Conference on Analytical Chemistry, 1943, vol. 2, pp. 359–370 : [Abstract]. Analyst, 1948, vol. 73, Mar., pp. 175–176).

Determination of Niobium in Steel. B. S. Krasilshchikov and N. M. Popova. (Zavodskaya Laboratoriya, 1945, vol. 11, pp. 512–515 : [Abstract]. Analyst, 1948, vol. 73, Mar., p. 176).

Photocolorimetric Determination of Chromium in Steel. I. V. Tananaev and K. A. Matveeva. (Zavodskaya Laboratoriya, 1945, vol. 11, p. 615 : [Abstract]. Analyst, 1948, vol. 73, Mar., pp. 173–174).

The Photometric Determination of Tungsten. C. H. R. Gentry and L. G. Sherrington. (Analyst, 1948, vol. 73, Feb., pp. 57–67). Tungsten is determined photometrically by using thiocyanate in conjunction with a reducing agent, but none of the reducing agents so far tried has been entirely satisfactory. The method described differs from previous methods in that the tungsten is reduced in hydrochloric acid solution by tin amalgam, before adding the thiocyanate. The conditions of acidity required for complete reduction, the effect of thiocyanate concentration, conditions for the stabilizing of the reduced state, and the optimum conditions of final acidity have been systematically investigated. Data are included on the interference of various anions and cations, and working instructions for the analysis of steel are given.—M. A. V.

Colorimetric Estimation of Tin and Bismuth.–Jean. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 23–25 June, 1947, 8th Congress, pp. 115–116). A method based on the precipitation of tin or bismuth as silicotungstate or phosphotungstate in the presence of hexamethylene tetramine in a solution of controlled acidity is described ; bismuth is first separated as a complex acid with thio-urea. Details are given both for low concentrations of these elements in steel and for the analysis of white metals containing them.—E. van S.

The Coleman Photoelectric Spectrophotometer. J. Orsag. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 23–25 June, 1947, 8th Congress, pp. 129–131). This spectrophotometer uses a grating to isolate a spectral region for absorptiometry, and a photocell with adjustable output to read percentage transmission directly. Calibration curves are given for the estimation of copper as cuprammonium complex, chromium as chromate, manganese as permanganate, and titanium and vanadium as pertitanate and pervanadate. The precision varies with the apparatus and in this case is of the order of 3% for the standard deviation of a single reading expressed as a concentration. Sources of error are clearly described.—E. van S.

Researches on the Spectrographic Analysis. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R. 1815 : H.M. Stationery Office). Apparatus and methods for spectrographic determination of iron and alloying elements used by the Nippon Steel Tube Co., Ltd., are described.—R. A. R.

A Direct Reading Spectrometer for Ferrous Analysis. S. H. Walters. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Proceedings, 1947, vol. 30, pp. 281–289). A description is given of a direct-reading spectrometer with which the elements in ferrous metals can be determined in about 40 sec. The intensity of the line for the element required is measured by a photoelectric cell by balancing the cell against a second one on which a reference line is projected. Checking and correcting the calibration are easily and rapidly carried out.—R. A. R.

A Rapid Spectrographic Control Method for Determination of Lime-Silica Ratios in Open-Hearth Slags. J. F. Woodruff. (American Institute of Mining and Metallurgical Engineers, Open-Hearth Conference, 1947, vol. 30, pp. 179–186). A detailed description is given of the equipment and technique for the determination of lime/silica ratios of slags. The result is obtained in 15 min., and the accuracy compares favourably with that of chemical methods. It can also be used for blast-furnace slags.—R. A. R.

45-Second Spectrochemical Analysis of Metals Possible by Direct-Reading Method. (Steel, 1948, vol. 121, Apr. 12, pp. 109–114). Brief details are given of the Quantometer, a special form of spectrometer capable of determining the elements having spectral lines readily excitable in the range of 2000–6000 Å. It is designed with a long focal curve along which slit-covered receivers can be moved to receive light from any desired line. Several lines can be determined together so that up to 11 elements can be determined in 45 sec. if the sample is properly prepared.—R. A. R.

Polarography in the Analysis of Metals and in the Foundry. M. Spalenka. (Fonderie, 1946, Special Issue, pp. 466–467). A brief survey is presented of the advantages and applications of polarographic analysis.—J. C. R.

Determination of Impurities in Electroplating Solutions. IV. Iron in Nickel Plating Baths. E. J. Serfass and W. S. Levine. (Monthly Review of the American Electroplaters' Society, 1946, vol. 33, Nov., pp. 1189–1197). In the method for determining iron in nickelplating baths the iron is separated from other metallic ions by precipitation with cupferron and the iron cupferride is extracted with amyl acetate and then returned to the aqueous solution by shaking the amyl acetate extract with nitric acid. The iron is then reduced with hydroxylamine hydrochloride, o-phenanthroline is added, and the *p*H is adjusted with sodium acetate. Finally, the light transmission of the ferrous o-phenanthroline complex is measured with a Klett-Sommerson colorimeter. R. A. R.

Determination of Impurities in Electroplating Solutions. V. Manganese in Nickel Plating Baths. E. J. Serfass and W. S. Levine. (Monthly Review of the American Electroplaters' Society, 1947, vol. 34, Mar., pp. 320–327). The manganese is oxidized to permanganate by sodium periodate in an acid mixture of phosphoric and perchloric acids. The transmission of the solution is then measured with a Klett Sommerson colorimeter with green filter No. 54.

Determination of Impurities in Electroplating Solutions. VI. Traces of Copper in Nickel Plating Baths. E. J. Serfass and W. S. Levine. (Monthly Review of the

American Electroplaters' Society, 1947, vol. 34, Apr., pp. 454–462). Copper is isolated from the other constituents in the plating bath by precipitation with 2-mercaptobenzothiazole and extraction of the precipitate with amyl acetate. The colour is then developed by addition of dibutyl amine and carbon disulphide. After diluting the solution to 25 ml. with ethyl alcohol, its transmittancy is measured using a Klett-Sommerson colorimeter with blue filter No. 42.

Determination of Impurities in Electroplating Solutions. VII. Traces of Silica in Nickel Plating Baths. E. J. Serfass, W. S. Levine, and P. J. Prang. (Plating, 1948, vol. 35, Feb., pp. 156–166). Two methods of determining silica in nickel-plating baths are described in detail: A gravimetric method using perchloric acid, and a colorimetric method based on the formation of the yellow silico-molybdate complex.

Determination of Impurities in Electroplating Solutions. VIII. Traces of Sodium and Potassium in Nickel Plating Baths. (Plating, 1948, vol. 35, Mar., pp. 260–263, 297). A method which makes use of the principle of a flame photometer is described for the rapid and accurate determination of sodium and potassium ions present as trace constituents in nickel-plating baths.—R. A. R.

INDUSTRIAL USES AND APPLICATIONS

Drier Rolls. G. L. Snyder. (American Pulp and Paper Mill Superintendents' Association: Iron and Steel, 1947, vol. 20, Nov., pp. 528–530). The design and merits of jacketed steel drier rolls for paper mills is discussed and their superiority over cast-iron rolls is pointed out.—R. A. R.

Haulage Ropes for Mining. N. Winchup. (Mining Electrical and Mechanical Engineer, 1947, vol. 28, Nov., pp. 143–150). The construction of wire haulage ropes is explained and examples are given of the calculation of bending stresses, rope friction, tub friction, pulley friction, and the forces in hauling loads up inclines. Finally, the lubrication of ropes is dealt with.—R. A. R.

Stainless Steels. G. E. Speight. (Journal of the Society of Dairy Technology, 1947, vol. 1, Oct., pp. 13–22). This is one of a number of papers included in a Symposium of Metals and Milk. The author reviews the types of stainless steel now commercially available for dairy use and other purposes.

Recent Applications of Nickel Steels and Cast Irons in the United States. (Revue du Nickel, 1947, July–Sept., pp. 33–43; [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Feb., p. 18). An account is given of some applications of nickel steels and cast irons as much from the point of view of mechanical construction as of the foundry.

Automotive Pistons and Their Development. B. Heward. (Journal of the Institution of Automotive and Aeronautical Engineers, 1947, vol. 7, June, pp. 67–75).

Substitute Metals for Copper in the Production of Tramway and Trolleybus Overhead Conductors. L. Albert. (Revue de l'Aluminium, 1948, vol. 25, Jan., pp. 3–12). In France composite steel–aluminium and other aluminium alloys have been used to replace copper for tramway and trolleybus conductors because of the shortage of copper during the war years. In this type of conductor, the lower portion is of steel to resist wear, whilst the aluminium part of the section carries the current. Examination has been made of composite steel–aluminium wires which have been in service for varying periods and their advantages and disadvantages compared with copper wires are discussed.—J. C. R.

Steels for Motor Vehicle Construction. (Journal of the Institution of Automotive and Aeronautical Engineers, 1947, vol. 7, Aug., pp. 99–106). This is a report by the Standards Committee of the Institution of Automotive and Aeronautical Engineers which surveyed the requirements of the automobile industry in Australia with a view to reducing the variety of materials required so that they could be produced in economic quantities. The specifications of the steels for various applications and methods of testing are given.—R. A. R.

Steel Cord Cased Pneumatic Tyres. (Engineer, 1948, vol. 185, Mar. 5, pp. 238–239). Particulars are given of a steel-cord pneumatic tyre now being tested on commercial vehicles. Each cord consists of 21 strands of 0·006-in. dia. wire, and a four-ply steel-cord tyre is expected to be equivalent to a sixteen-ply rayon-cord tyre.—R. A. R.

Steel Castings, Uses as Engineering Materials. J. A. Rassenfoss. (American Society for Testing Materials: American Foundryman, 1947, vol. 12, Dec., pp. 38–44: Steel, 1947, vol. 121, Dec. 15, pp. 90, 91, 102–106). Applications of steel castings are reviewed in a manner indicating the wide sphere in which they can be employed with advantage.—R. A. R.

Investigation of the German Needle Industry. (British Intelligence Objectives Sub-Committee, 1948, Final Report No. 1456: H.M. Stationery Office).

Metallurgical Examination of Japanese 37 mm. High Explosive Shells. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1523: H.M. Stationery Office).

Metallurgical Examination of Japanese 70 mm. and 75 mm. H.E. Ammunition. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1524: H.M. Stationery Office).

Metallurgical Examination of a Japanese Bomb Hoist and Release. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1534: H. M. Stationery Office).

Metallurgical Examination of the Hardware from Japanese and German Parachute Harness. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1542: H.M. Stationery Office).

Metallurgical Examination of Japanese Oxygen and Carbon Dioxide Cylinders. (British Intelligence Objectives Sub-Committee, 1948. Report No. B.I.O.S./J.A.P./P.R./1543: H.M. Stationery Office).

Metallurgical Examination of Japanese Aircraft Armor Plate. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1544: H.M. Stationery Office).

Metallurgical Examination of a Japanese Rifle 7·7 mm., (Caliber ·303″), Model 99. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1547: H.M. Stationery Office).

Metallurgical Examination of One Half Inch Thick Japanese Aircraft Armour Plate from "Oscar" Aircraft. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1683: H.M. Stationery Office).

Metallurgical Investigation of Japanese 81 mm. Mortars. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1515: H.M. Stationery Office).

Metallurgical Examination of a Japanese C/R 20 mm. Hotchkiss H.E. Shell for Model 98 AA Gun. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1516: H.M. Stationery Office).

Metallurgical Examination of a Japanese 1/3 KG. Anti-Parked Aircraft Bomb. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1517: H.M. Stationery Office).

Metallurgical Examination of a Japanese 7·7 mm.

Model 92 Heavy Machine Gun of 1938. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1518 : H.M. Stationery Office).

Metallurgical Examination of Japanese 25 mm. Hotchkiss Incendiary and H.E., Incendiary, Tracer Rounds. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1521 : H.M. Stationery Office).

Metallurgical Examination of a Japanese 57 mm. Tank Gun, Model 97. (British Intelligence Objectives Sub-Committee, 1948, Report No. B.I.O.S./J.A.P./P.R./1535 : H.M. Stationery Office).

HISTORICAL

Metals and Mankind: from Anglesey to Hiroshima. H. O'Neil. (Metallurgia, 1948, vol. 37, Mar., pp. 231–237). The history of a technical subject forms a link with its human aspect. In tracing this link the author gives some historical particulars of a few isolated periods connected with the development of metal-working in Britain, emphasis being placed on the ductility of the metals worked. Finally, achievements in physical metallurgy which have led up to the production of the atomic bomb are noted and the plea is made that British colleges should play their part with the Universities of Yale and Chicago in preparing plans for its international control.—R. A. R.

Prices of Iron and Steel in 1578. F. C. Morgan. (Transactions of the Newcomen Society, 1942–43, vol. 23, pp. 131–132). A document from the archives of the City of Hereford indicating the prices of wrought iron, steel, and charcoal in 1578 is reproduced with notes on the weights and measures used.—R. A. R.

Early Engineering and Ironfounding in Cornwall. R. Jenkins. (Transactions of the Newcomen Society, 1942–43, vol. 23, pp. 23–35). An account is given of the history of engineering and ironfounding in Cornwall from about 1777 to 1880.—R. A. R.

The Water Wheels of Sheffield. A. Allison. (Society for the Preservation of Old Sheffield Tools : Engineering, 1948, vol. 165, Feb. 13, pp. 165–168). A review of the history of the water mills which have supplied power for industrial purposes in the Sheffield area during the last 750 years is presented. The account also covers the history of iron making and forging, as well as slitting and grinding.—R. A. R.

History of the Grated Hearth, the Chimney, and the Air Furnace. J. N. Goldsmith and E. Wyndham Hulme. (Transactions of the Newcomen Society, 1942–43, vol. 23, pp. 1–12). An account is given of the history of the natural draft or air furnace from its inception in the prehistoric roasting of flesh onwards to the eighteenth century.—R. A. R.

The Work of Vannoccio Biringuccio of Sienna on Foundry Technique in the XVIth Century. G. Somigli. (Congrés de Fonderie, Rome, 6–9 May, 1939 : Bulletin de l'Association Technique de Fonderie, 1940, Mar.–Apr., pp. 57–60). An account is given of the life and work of Vannoccio Biringuccio, with frequent references to his Pirotechnica.—J. C. R.

Iron and Steel Metallurgy through the Ages. G. Delbart. (Association Technique de Fonderie, 22 Oct., 1943). The author traces the history of the metallurgy of iron and the methods of manufacture from the earliest times. The second part of the paper deals with the history of the metallography of iron and steel.—J. C. R.

Grand Crossing Tack Co. Interstate Iron & Steel Co. Republic Steel Corp. K. B. Lewis. (Wire and Wire Products, 1948, vol. 23, Feb., pp. 147–150, 181–182). An outline is given of the history of a wire-making company in the United States which began as the Grand Crossing Tack Co., and eventually became the wire department of the Republic Steel Corporation.

A Prehistoric Iron Ring. (Bulletin of the British Cast Iron Research Association, 1948, vol. 9, Mar., pp. 133–136). Translations are given of Czech correspondence by Dr. Píšek and Professor Jareš relating to the prehistoric iron ring found at Byčí Skála (*see* Journ. I. and S.I., 1948, vol. 158, Mar., p. 413).

A Eulogy of Iron by Thomas Dekker, in 1629. H. R. Schubert. (Journal of The Iron and Steel Institute, 1948, vol. 158, Mar., p. 322).

Personal Recollections of Early High Speed Steel (1904–1906). J. H. Hall. (Metal Progress, 1948, vol. 53, Feb., pp. 211–215).

Metallurgy in America, 1917–1947. (Metal Progress, 1948, vol. 53, Jan., pp. 75–78). A year-by-year schedule is presented of developments witnessed by the American Society for Metals during the past thirty years.—J. R.

MISCELLANEOUS

Production of Industrial Oxygen. M. Ruhemann. (Times Review of Industry, 1948, Apr., pp. 18–21). An outline is given of different processes for producing oxygen with emphasis on recent technical improvements which lower the cost of production. A comparison is made of costs in Great Britain, Germany, Russia, and the United States. The economic aspects of the use of oxygen in blast-furnaces, open-hearth furnaces, and Bessemer converters are briefly reviewed ; its use for making ferrosilicon appears attractive. The Lurgi process of gasifying coal at a pressure of 20 atm. in the presence of steam and oxygen is described. The conclusion is that there is a measure of exaggeration and over-optimism in the belief that oxygen can now be produced extremely cheaply, and that its large-scale use can vastly increase Britain's industrial productivity. —R. A. R.

Corrigenda

The following corrections to Abstracts in the May *Journal* should be noted : Page 84, column 2, abstract 10 : the author's name should be M. Czyzewski ; page 86, column 2, abstract 5 : the author's name should be W. Sznuk ; page 99, column 1, abstract 2 : the reference should be : Société Française de Métallurgie : Révue de Métallurgie . . . ; page 101, column 2, abstract 7 : the author's name should be O. Puchner ; page 110, column 2, abstract 7 : the author's name should be P. Gillain.

Use and Production of Oxygen for Blast Enrichment. II—Manufacture of Low-Cost Oxygen. P. C. Keith and D. W. Wilson. (American Institute of Mining and Metallurgical Engineers : Blast Furnace, Coke Oven, and Raw Materials Conference, Proceedings, 1947, vol. 6, pp. 55–67). A history of the development of modern oxygen-producing plants is given with notes on the economic aspects of their construction and operation. A flow sheet for a low-pressure plant is shown and the plants of this type in the United States are briefly described. The capital cost for such plants rises from $940,000 for producing 100 tons/day to $2,950,000 for 1000 tons/day of 90% to 96% purity, the production costs being $4.29 and $2.01 per ton respectively for these capacities. The cost of power for the compressors is of primary importance, and if surplus heat is available at low cost from synthetic petrol plants or other sources

the cost of production could be very considerably reduced.—R. A. R.

Method of Studying Equilibria in Simultaneous Reactions. M. Pourbaix. (Revue de Métallurgie, Mémoires, 1947, vol. 44, Sept.–Oct., pp. 292–301). The chemical reactions with which metallurgists are concerned are often complex transformations resulting from the simultaneous occurrence of several reactions more or less distinct. The calculation of the equilibria of such cases is often laborious. In the method of studying these equilibria outlined in this article the variable factors characterizing each of these equilibria are divided into two groups; two of the factors, which are the same for all the equilibria, are regarded as independent variables, and are inserted as ordinates and abscissae respectively in a two-dimensional diagram; the other factors are considered as parameters. Thus, the equilibrium characteristics of each of the reactions can be represented in the diagram by a family of lines, of which each one corresponds to a given value of the parameter. After brief references to Scheffer's law concerning simplified representation of the influence of temperature on the equilibrium constant and the usually weak influence of the variation of the heat of reaction with temperature, Trouton's law of the apparent constancy of the ratio of the latent heat of vaporization to the absolute boiling point at 1 atm. pressure, and the Le-Chatelier/Matignon law (in certain cases, and particularly where reaction involves only a single gas) that the ratio of the heat of reaction to the absolute temperature at which the pressure of gas is 1 atm. is fairly constant, the application of the method of study described to systems comprising one constituent (oxygen, in which molecules break down to atoms), two constituents (carbon–oxygen, zinc–oxygen) and three constituents (zinc–carbon–oxygen) are described. The systems hydrogen–oxygen, sulphur–oxygen and iron–chlorine are also touched on. In conclusion the phase rule is discussed in relation to the system of studying equilibria in simultaneous reactions described in this article.—A. E. C.

The Organization of Industrial Research in Great Britain. B. J. A. Bard. (British Science News, 1948, vol. 1. No. 7, pp. 19–21). A brief history of the development of industrial research in Great Britain is given, and the present organization is described.—R. A. R.

The New Baillieu Laboratories at Melbourne University. J. N. Greenwood. (Metal Treatment, 1948, vol. 15, Spring Issue, pp. 15–16). A fund has recently been established in the University of Melbourne to found a School of Metallurgical Research; a section on physical metallurgy is to work in conjunction with it. The Baillieu family in Melbourne has contributed a large sum to the building fund. The Baillieu laboratories are now under construction and a description of them and some of the equipment already obtained is given.—R. A. R.

L'Institut de Recherches de la Sidérurgie. H. Malcor. (Métallurgie, 1948, vol 80, Apr., pp. 21–23). An account is given of the organization and functions of this French iron and steel research association, with particulars of the fields in which research work will be undertaken. J. C. R.

Heat Transfer to Gases through Packed Tubes. M. Leva and M. Grummer. (Industrial and Engineering Chemistry, 1948, vol. 40, Mar., pp. 415–419). The equation calculating the coefficient of heat transfer developed in an earlier work takes no account of the uniformity, shape, thermal conductivity, and surface roughness of the packing material. It is now shown that the equation applies to mixed packings provided a correct average value is chosen for the packing diameter. Heat-transfer coefficients increased with increasing thermal conductivity of the packing, and were slightly higher for rougher particles. A possible mechanism of heat flow through the core of packed tubes is discussed. Full experimental data are given for a variety of packing materials in the form of spheres, cylinders, Raschig rings, and sharp and rounded irregular shapes.—M. A. V.

Hydrogen-Zeolite Treated Water Dissolves Boiler Superheater Scale. T. L. B. Webb and J. D. Yoder. (Power, 1948, vol. 92, No. 1, pp. 99–101, 140, 142, 143: Chemical Abstracts, 1948, vol. 42, Apr. 10, col. 2372). Uninhibited 0·01–0·03% acid, such as might be prepared by passing a normal water through hydrogen-zeolite softeners has been used successfully to remove superheater scale. It has also been used in boilers and for external clearing. A suggested procedure is outlined.

Notes on Changing Feedwater Treatment in Boilers. C. W. Sparks. (Power Plant Engineering, 1947, vol. 53, No. 12, pp. 96–97: Chemical Abstracts, 1948, vol. 42, Apr. 10, col. 2372). Changing from internal to external treatment brings about certain different reactions. The most interesting involve alkalinities and concentration.

BOOK NOTICES

American Society for Testing Materials. "*A.S.T.M. Specifications for Steel Piping Materials.*" 8vo, pp. viii + 308. Philadelphia, 1948: The Society (Price $3.00).

This publication contains all the specifications for carbon steel and alloy steel pipe and tubing issued by the American Society for Testing Materials. The specifications cover: (1) Pipe used to convey liquids, vapours, and gases at normal and elevated temperatures; (2) still tubes for refinery service; (3) heat exchanger and condenser tubes; and (4) boiler and superheater tubes. There are also included specifications for the following materials used in pipe and related installations: (1) Castings; (2) forgings; (3) bolts; and (4) nuts.—R. E.

Baker, H. W. "*Modern Workshop Technology.*" Part 1. "*Materials and Processes.*" 8vo, pp. viii + 445. Illustrated. London, 1948: Cleaver-Hume Press, Ltd. (Price 28*s.*).

This is a well-planned volume by a well-balanced team of writers. It is a suitable text-book for engineering students taking metallurgy as a subject for a degree course. The inclusion of numerous typical examination questions makes it a suitable guide for teachers in charge of such courses. The sketches are excellent, the photography reasonably good, and the chapter bibliography well chosen. Each section is modern in detail and the section on physical metallurgy contains many items of interest not dealt with in any other metallurgical textbook to my knowledge.—W. A. Naish.

Fisher, J. C. "*The Metallurgist Johann Conrad Fischer, 1773–1854, and His Relations with Britain.*" 8vo, pp. 53. Illustrated, 1947. Schaffhausen, Switzerland: G. Fischer, Ltd.

This memoir, issued in English by the firm founded by J. C. Fischer at the beginning of the last century, describes the career of an active and able metallurgist who may be regarded as the father of the Swiss metal industry. It was in 1804 that he produced the first crucible cast steel on the Continent, although Hunts-

man, in England, had invented his process in 1740. Unlike Huntsman, however, Fischer, did not submit his iron to the preliminary process of cementation, but carburized it directly in the crucible.

The long accounts of Fischer's visit to England are particularly interesting. His first visit was in 1794–95, during his apprenticeship, when he worked with an engineering fitter in London. From 1814 onwards he visited this country eight more times, and he records with pleasure the warm welcome that he received from such men as James Watt and Michael Faraday, who opened their laboratories and workshops to him. This short but well produced and illustrated memoir describes the close relations which he maintained with British scientific men and industrialists.—C. H. DESCH.

UHLIG, H. H. "*Corrosion Handbook*." 8vo, pp. 1188. New York, 1948 : John Wiley and Sons, Inc. ; London : Chapman and Hall, Ltd. (Price $12.00).

This volume, edited by H. H. Uhlig, is sponsored by the Electrochemical Society of New York, and royalties from its sale will be used to support other corrosion activities. The handbook is a condensed summary of corrosion information and includes within its scope a cross-section of scientific data and industrial experience. The nine sections comprising the volume are devoted to : Corrosion Theory ; Corrosion in Liquid Media, the Atmosphere, and Gases ; Special Topics in Corrosion ; High-Temperature Corrosion ; High-Temperature-Resistant Materials ; Chemical-Resistant Materials ; Corrosion Protection ; Corrosion Testing ; and Miscellaneous Information. A glossary of terms used in corrosion is appended.—R. E.

NEW PUBLICATIONS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Blast Furnace, Coke Oven, and Raw Materials Committee of the Iron and Steel Division, Proceedings*." Vol. 6. Cincinnati Meeting, April 21–23, 1947. 8vo, pp. 199. Illustrated. New York, 1948 : The Institute.

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Proceedings of the Thirtieth Conference, National Open-Hearth Committee of the Iron and Steel Division. Cincinnati, Ohio. April 21–23, 1947*." Volume 30, pp. 318. New York : The Institute.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*A.S.T.M. Specifications for Steel Piping Materials*." 8vo, pp. viii + 308. Philadelphia, 1948 : The Society. (Price $3.00).

AMERICAN WELDING SOCIETY. "*The Fracture of Metals*." By M. Gensamer, E. Saibel, J. T. Ransom, and R. E. Lowrie. 8vo, pp. 84. New York, 1948 : American Welding Society. (Price $1.00).

BARTOCCI, A. "*I Metalli e L'Acciaio*." Trattato di Scienza dei Metalli e di Siderurgia. La. 8vo, pp. xix + 1001. Illustrated. Terni : Poligrafico Alterocca Editore.

BENDZ, W. L., and C. A. SCARLOTT. "*Electronics for Industry*." 8vo, pp. x + 501. New York, 1947 : John Wiley and Sons, Inc. ; London : Chapman and Hall, Ltd. (Price 30*s*.).

BOAS, W. "*An Introduction to the Physics of Metals and Alloys*." New York : John Wiley and Sons, Inc. (Price $3.50).

FROCHT, M. M. "*Photoelasticity*." Volume 2, pp. 506. New York, 1948 : John Wiley and Sons, Inc. (Price $10.00).

GILLE, B. "*Les origines de la grande industrie métallurgique en France*." 8vo, pp. 248. Paris : Editions Domat Montchrestien. (Price 750 francs).

GONNER, O. "*Das Schweissen von Betriebsmitteln*." 8vo, pp. 148. München, 1947 : Carl Hanser Verlag. (Price 6.50 RM.).

HALL, F. P., and H. INSLEY. "*Phase Diagrams for Ceramists*." Pp. viii + 152. Columbus, Ohio, 1947 : American Ceramic Society.

HARRINGTON, R. H. "*The Modern Metallurgy of Alloys*." Pp. 208. New York, 1948 ; John Wiley and Sons, Inc. (Price $3.50).

HERBERS, H. "*Härten und Vergüten des Stahles*." 5. völlig umbearb. u. verm. Aufl., 8vo, pp. 68. Berlin and Göttingen, 1947 : Springer-Verlag. (Price 3.60 RM.).

JACQUET, P. A. "*La Polissage Electrolytique des Surfaces Métalliques et ses Applications*." Tome 1. "*Aluminium, Magnésium, Alliages légers*." La. 8vo, pp. xiii + 359. Paris, 1948 : Editions Métaux. (Price 3600 francs).

LOVELL, B. "*Electronics and their Application in Industry and Research*." 8vo, pp. xvi + 660. London, 1947 : Pilot Press. (Price 42*s*.).

MELBOURNE UNIVERSITY. "*The Failure of Metals by Fatigue*." Proceedings of a Symposium held in the University of Melbourne, Dec. 2nd–6th, 1946, under the ægis of the Faculty of Engineering. With a Foreword by H. J. Gough, F.R.S. 8vo, pp. xvi + 505. Illustrated. Melbourne, 1947 : Melbourne University Press. (Price 42*s*.).

MINISTRY OF FUEL AND POWER. "*Fuel and the Future*." The Proceedings of a Conference held in London on Oct. 8, 9, and 10, 1946, under the auspices of the Fuel Efficiency Committee. In three volumes, 8vo. Vol. 1, pp. vi + 370 (Price 6*s*.). Vol. 2, pp. vi + 374. (Price 6*s*.). Vol. 3, pp. vi + 211. (Price 3*s*. 6*d*.). London, 1948 : H.M. Stationery Office.

MORISSET, P. "*Répertoire technique des applications industrielles du chrome dur*." 8vo, pp. 220. Paris : Centre d'Informations du Chrome Dur. (Price 600 francs).

NÉGRE. J. "*Le Soudage Electrique par Résistance*." 8vo, pp. 432. Illustrated. Paris, 1948. Publications de la Soudure Autogène. (Price 1350 francs).

NAUMANN, F. "*Das Zementsand-Formverfahren*." 8vo, pp. 79, Berlin, 1947 : Schiele und Schön. (Price 4.50 RM.).

PALMER, F. R. and G. V. LUERSSEN. "*Tool Steel Simplified*." Second Edition, 8vo, pp. 564. Reading, Pennsylvania, 1948 : Carpenter Steel Company. (Price $2.00).

PASCHKIS, V. "*Industrial Electric Furnaces and Appliances*." Vol. 2, pp. 320. New York and London, 1948 : Interscience Publishers, Inc. (Price 48*s*.).

SISCO, F. T. "*Modern Metallurgy for Engineers*." Second Edition. New York : Pitman Publishing Corporation. (Price $5.00).

UHLIG, H. H. "*Corrosion Handbook*." 8vo, pp. 1188. New York, 1948, John Wiley and Sons, Inc. ; London : Chapman and Hall, Ltd. (Price $12.00).

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Einsparung von Schmiermitteln*." 8vo, pp. 32. Düsseldorf, 1947 : Verlag Stahleisen. (Price 2.25 RM.).

WOLDMAN, N. E. "*Metal Process Engineering*." 8vo, pp. 291. New York, 1948 : Reinhold Publishing Corporation. (Price $5.00).

ZEYEN, K. L. und W. LOHMANN. "*Schweissen der Eisenwerkstoffe*." 2 Aufl. (Stahleisen Bucher Bd. 6). Pp. 456. Illustrated. Düsseldorf, 1948 : Verlag Stahleisen : (Price 37 RM.).